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Three-Dimensional Analysis of Maxillary Sinus for Age Estimation in Forensic Human Identification

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Aim: To assess the validity of the maxillary sinus in age estimation using CBCT.
Materials and Methods: This study analyzed 230 cone beam computed tomography (CBCT) scans of patients over the age of 18. The patients' records for CBCT were obtained from the archives of the Department of Oral and Maxillofacial Radiology at Ain Shams University's Faculty of Dentistry. The patients were categorized into two age groups: Group A, consisting of individuals under 40 years old, and Group B, comprising those over 40 years old. Linear measurements of the maxillary sinus were taken, along with assessments of the three-dimensional volume.
Results: The results in this study revealed there was a Weak Negative correlation of age with volume, height, width, and depth. Also the older age group exhibited a statistically significant reduction in mean height, width, depth, and volume compared to the younger age group. Furthermore, the volume had the largest correlation with age.
Conclusion: The application of the maxillary sinus for age estimation has limited accuracy; however, the volume of the maxillary sinus serves as the most reliable indicator for age estimation in human identification.

Keywords: Maxillary sinus, Age estimation, Human identification, Radiography

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Introduction

Forensic medicine involves the integration of medical expertise with legal matters and investigations. It includes various medical disciplines focused on the assessment and diagnosis of individuals who have suffered injuries or have died under atypical or questionable conditions. This area is vital to the criminal justice system, as it supplies scientific evidence that can be utilized in legal proceedings. Forensic medicine plays a crucial role in revealing the truth in legal matters, aiding in the identification of victims, establishing causes of death, and supplying vital evidence that can facilitate the resolution of criminal inquiries. [1, 2, 3]

The maxillary sinus, the largest of the paranasal sinuses situated within the maxilla, has become increasingly important in the fields of forensic anthropology as a key anatomical feature for examining skeletal remains. Its distinct morphological characteristics display notable sexual dimorphism and variations associated with age, rendering it a crucial resource for forensic experts aiming to create biological profiles of unidentified individuals. Evaluating the maxillary sinus can yield essential insights in multiple scenarios, such as determining sex, estimating age, and aiding in identification during criminal investigations. [4, 5, 6]

Recent developments in imaging technologies, particularly cone beam computed tomography (CBCT), have significantly enhanced the precision and reliability of maxillary sinus examinations. These imaging techniques enable detailed visualization of the dimensions and morphology of the sinus, facilitating quantitative assessments that enhance the accuracy of forensic investigation. As a result, the maxillary sinus serves not only as a key anatomical landmark but also as an essential resource in the ongoing efforts to improve forensic methodologies and contribute to the pursuit of justice. [6, 7, 8, 9]

The application of the maxillary sinus for age estimation remains a topic of debate. Consequently, this study aims to explore the effectiveness of the maxillary sinus in estimating age through the use of CBCT technology.

Materials and methods

Sample selection

Patient records for CBCT were retrieved from the archives of the department of Oral & Maxillofacial Radiology, Faculty of Dentistry, Ain Shams University. Clearance for the study was obtained from the institutional ethics Committee (FDASU_Rec EM012105).

According to the statistically calculated sample size, and after exclusion of cases with fractured maxillary sinus walls or facial bones, congenital diseases, craniofacial deformities, and patients less than 18 years of age, 230 cases were analyzed. The age of the selected cases wasn't less than 18 years old. Patients divided into 2 age groups:

A. Less than 40 years old
B. More than 40 years old

CBCT acquisition and Data analysis

All scans were retrieved using i-CAT Next Generation scanner (Imaging Sciences International, Hatfield, PA, United States) operating at tube voltage 120 kvp. Image detector was 20 x 25 cm flat panel detector. Scans were selected with maximum FOV to cover the maxillary sinus on both sides. All measurements were performed using the OnDemand 3D software application (Cybermed.Co, Seoul, Korea) version 1.0 (Build 1.0.10.7462) (x64 Edition). After going through different slices in axial and coronal sections, the greatest measurements were obtained.

Linear measurements of maxillary sinus were

1) The height of maxillary sinus was measured on the coronal view with the linear measuring tool. The height was measured from the deepest point of the inferior wall to the highest point of the superior wall. Figure (1.A)
2) The depth of maxillary sinus was measured on the axial view with the linear measuring tool. The depth was measured antero-posteriorly from the most anterior point of the anterior wall to the most posterior point of the posterior wall. Figure (1.B)
3) The width of maxillary sinus was measured on the axial view with the linear measuring tool. The width was measured from the outermost point of the lateral wall of the maxillary sinus to the most medial point of the medial wall. Figure (1.C)

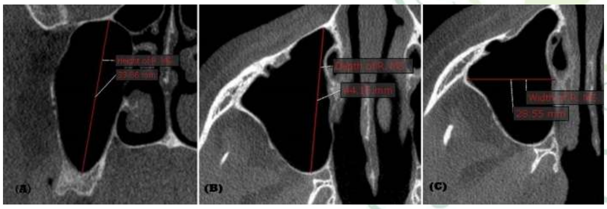

Figure 1: (A)The height of the maxillary sinus on the coronal view measured from the deepest point of the inferior wall to the highest point of the superior wall. (B)The depth of maxillary sinus was measured on the axial view with the linear measuring tool. The depth was measured antero-posteriorly from the most anterior point of the anterior wall to the most posterior point of the posterior wall. (C)The width of maxillary sinus on the axial view, measured from the outermost point of the lateral wall of the maxillary sinus to the most medial point of the medial wall.

The volumetric analysis of the sinus

-After data loading, the 3D module was chosen

- The ROI area was adjusted by dragging the dotted lines on the multiplanar (MPR) windows.

-The threshold was adjusted to view the maxillary sinus through the fine tuning bar. It ranged between (-500: -300).

- The segmentation process was conducted utilizing the object mask tool, which involved selecting random points within the maxillary sinus region. By employing the region growing technique, the software was able to automatically calculate the volume of the maxillary sinus in cubic centimeters (cm^3). Figure (2)

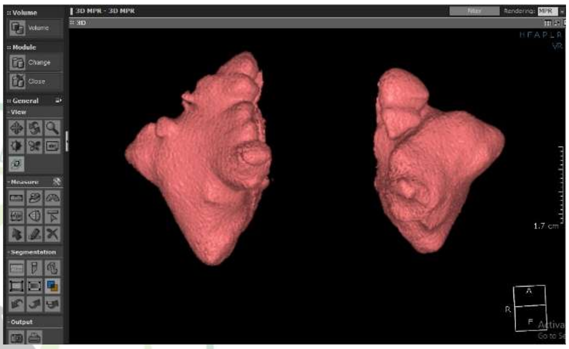

Figure 2: The volume of Maxillary sinus.

Statistical analysis

All Data were collected, tabulated and subjected to statistical analysis. Statistical analysis was performed by SPSS in general (version 20), while Microsoft office Excel was used for data handling and graphical presentation. Simple linear regression analysis was used in case of age and volume alone. Quantitative variables were described by the Mean, Standard Deviation (SD), the Range (Minimum – Maximum), Standard Error (SE) and 95% confidence interval of the mean. Independent samples t test was applied for comparing two groups means. Pearson correlation coefficient was used for correlation analysis.

Results

The Pearson correlation coefficient was employed for the correlation analysis. The coefficient for the relationship between age and height was found to be -0.147, with a p-value of 0.02598. In contrast, the correlation between age and width yielded a Pearson correlation coefficient of -0.135, accompanied by a p-value of 0.04116. Additionally, the correlation coefficient for age and depth was -0.128, with a p-value of 0.05249. Finally, the correlation between age and volume demonstrated a Pearson correlation coefficient of -0.298, with a p-value of 0.000. (Table 1,2 Figures 3,4)

Discussion

Forensic medicine frequently utilizes a range of radiological methods to assist in the age estimation. A notable technique involves the radiological assessment of the maxillary sinuses. These air-filled cavities, situated within the maxilla, exhibit unique characteristics akin to fingerprints, thereby enhancing their utility in forensic analysis. As the largest of the paranasal sinuses, the maxillary sinus possesses distinct anatomical features that can be compared with antemortem radiographs to facilitate the identification of unidentified remains. Research has shown that the maxillary sinus often remains preserved even when the skull and surrounding bones are severely distorted.[1, 2]

There is still controversy regarding the use of the maxillary sinus in age estimation; therefore, the aim of the current study was to assess the validity of the maxillary sinus in age estimation using CBCT.

The present study was conducted utilizing CBCT. This imaging modality presents several significant benefits that improve the accuracy, dependability, and efficiency of forensic analyses. Its capacity to deliver high-resolution, non-invasive, and comprehensive imaging significantly enhances the precision and reliability of age estimation. Additionally, it facilitates the accurate measurement of maxillary sinus dimensions, resulting in elevated accuracy rates in age identification. Moreover, CBCT allows for the acquisition of detailed quantitative data regarding the maxillary sinus, encompassing parameters such as volume, height, depth, and width. This quantitative dimension is essential for conducting statistical analyses that aid in age estimation.[4, 9, 10, 11]

The study utilized a sample of 230 cases, specifically selected to include both maxillary sinuses and individuals aged 18 years or older. The minimum age requirement was set at 18 years to ensure that individuals have reached full growth and development. Exclusions were made for cases involving fractured walls of the maxillary sinus or facial bones, congenital disorders, and craniofacial anomalies to prevent any influence on the size and dimensions of the maxillary sinus.

The independent samples t-test was conducted to compare the mean variables between the two age groups. In terms of height, the older age group exhibited a statistically significant lower mean height compared to the younger age group. Similarly, for width, the older age group showed a statistically significant reduction in mean width relative to the younger group. Regarding depth, the older age group also had a statistically significant lower mean depth than the younger age group. Finally, for volume, the older age group demonstrated a statistically significant decrease in mean volume compared to the younger age group.

The Pearson correlation coefficient was employed to assess the strength of the linear relationship between two variables. The analysis revealed a weak negative correlation between age and height, which is statistically significant. Similarly, a weak negative correlation was found between age and width, also statistically significant. In contrast, the correlation between age and depth was weak and statistically non-significant. For volume, there exists a weak negative correlation with age that is statistically highly significant.

Table 1: Descriptive Statistics of different parameters

Height	N	Mean	SD	SEM	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Less than 40 years	96	39.06	5.13	0.52	38.02	40.09	25.20	54.67
More than 40 years	134	37.05	5.35	0.46	36.13	37.96	18.27	54.85
All cases	230	37.88	5.34	0.35	37.19	38.58	18.27	54.85
Width								
Less than 40 years	96	27.12	3.45	0.35	26.43	27.82	17.92	34.50
More than 40 years	134	25.99	4.17	0.36	25.27	26.70	14.89	40.32
All cases	230	26.46	3.92	0.26	25.95	26.97	14.89	40.32
Depth								
Less than 40 years	96	39.61	3.08	0.31	38.99	40.24	30.24	46.61
More than 40 years	134	38.64	3.63	0.31	38.02	39.26	24.06	45.96
All cases	230	39.05	3.44	0.23	38.60	39.50	24.06	46.61
Volume								
Less than 40 years	96	20.93	5.59	0.57	19.80	22.06	13.13	33.15
More than 40 years	134	16.96	5.48	0.47	16.02	17.89	5.51	33.01
All cases	230	18.62	5.85	0.39	17.85	19.38	5.51	33.15

Table 2: Independent samples t test for comparing the mean values of the variables between the two age groups

							95% Confidence Interval of the Difference				
Height	N	Mean	SD	SEM	Mean Difference	SED	Lower	Upper	t	df	P Value
Less than 40 years	96	39.06	5.13	0.52	2.01	0.70	0.62	3.40	2.86	228	0.00464*
More than 40years	134	37.05	5.35	0.46							
Width											
Less than 40 years	96	27.12	3.45	0.35	1.14	0.52	0.12	2.16	2.19	228	0.02934*
More than 40years	134	25.99	4.17	0.36							
Depth											
Less than 40 years	96	39.61	3.08	0.31	0.97	0.46	0.07	1.87	2.12	228	0.03486
More than 40 years	134	38.64	3.63	0.31							
Volume											
Less than 40 years	96	20.93	5.59	0.57	3.98	0.74	2.52	5.43	5.38	228	0.0000**
More than40 years	134	16.96	5.48	0.47							

The older age group exhibited a statistically significant reduction in mean height, width, depth, and volume when compared to the younger age group.
P value > 0.05 is insignificant, *p value < 0.05 is significant, **p value < 0.001 is highly significant

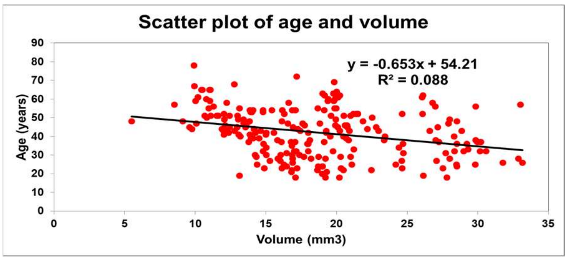

Figure 3: scatter plot of age and volume. The points were widely spread around the regression line indicating low correlation Pearson Correlation coefficient R=-0.298 R2 = 0.088
Small R squared value indicating that the model wasn't suitable for proper prediction.

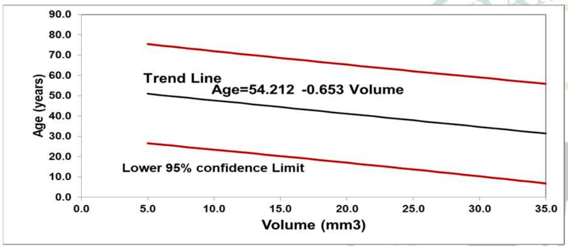

Figure 4: Regression line of age and volume with 95% confidence interval. Due to the low correlation and small R squared value, the confidence interval for prediction were too large as shown in the diagram by the two red lines around the trend line .In fact the deviation from trend line was about +/- 24 years makes the prediction of no practical value.

The previous analysis indicates that volume exhibits the strongest correlation with age, prompting a simple regression analysis of these two variables. The scatter plot illustrating the relationship between age and volume displays a regression line with a slight negative slope, while the data points are widely dispersed around this line, suggesting a low correlation between age and volume.

The use of maxillary sinus dimensions for age estimation remains a topic of debate. Some studies in the literature suggest that the volume of the maxillary sinus can serve as an indicator of age, while others propose that its height and depth may also be relevant. Conversely, some research indicates that the maxillary sinus is not a viable tool for age estimation.

Numerous studies in the current literature have utilized various imaging modalities to evaluate the maxillary sinus for the purpose of age estimation. In accordance with our study, Rani et al.[12] conducted a study involved 60 participants, consisting of 30 males and 30 females, aged between 21 and 73 years. Each participant underwent MRI examinations, during which measurements of width, height, and depth were taken. The volume of each maxillary sinus was calculated using a specific equation. The analysis of age groups revealed significant differences in the four variables (volume, width, depth, and height), all of which decreased with advancing age. Additionally, the study found no statistically significant difference between the estimated age and the actual age of the patients, suggesting that the dimensions and volume of the maxillary sinuses can serve as indicators for age estimation.

Moreover, Koç et al.[13] performed a study involving 164 CBCT scans. They examined the applicability of sphenoid sinus and maxillary sinus volumes in assessing gender and age through the analysis of CBCT images from a population in Eastern Turkey. The results indicated no significant correlation between age and any of the sinus volumes.

Also, Hamdy et al.[14] performed an analysis of 120 CBCT images of the maxillary sinus, maintaining an equal ratio of male to female participants. The subjects were categorized into three age groups: 20-30, 30-40, and 40-50 years. The height, depth, and width of the maxillary sinus were measured. The study revealed no statistically significant differences in the mean dimensional values across the various age groups.

Furthermore, Ceena et al.[15] performed an analysis involving 80 CBCT scans, with participants aged between 20 and 54 years. They divided the subjects into three distinct age categories: ≤25 years, 25–30 years, and >30 years. The objective of the study was to evaluate the accuracy of the dimensions and volume of the maxillary sinus for the purposes of sex and age identification. The specific parameters assessed included the superoinferior and mediolateral dimensions, as well as the overall volume of the maxillary sinus. Upon analysis, the researchers observed that the measurements of superoinferior and mediolateral dimensions, along with the sinus volume, were consistent with age, showing no statistically significant differences. This suggested that age didn't play a significant role in determining the size of the maxillary sinus.

On the other hand, Abd-alla et al.[16] conducted an investigation on the maxillary sinus using a sample of 110 cadavers. The researchers assessed the length, width, and height of both the right and left maxillary sinuses. The subjects were categorized into four distinct age groups: group 1 (20–29 years), group 2 (30–39 years), group 3 (40–49 years), and group 4 (50–59 years). They found that Group 1 (ages 20–29) exhibited a lower mean value compared to the other age groups. Group 2 (ages 30–39) demonstrated an increase in both the width and length of MS, while the 40 to 49 age group experienced a slight rise in both dimensions. The final age group recorded the highest mean value.

On the contrary, Barros et al.[17] conducted a study utilizing CBCT images from 238 patients to assess the height, width, and length of the maxillary sinus on both sides. The participants were categorized into three age groups: 6-11 years, 12-17 years, and 18 years or older. The findings indicated that the 12 to 17-year age group exhibited greater maxillary sinus height and depth compared to the 6 to 11-year group. Additionally, individuals aged 18 years and older showed a significantly greater maxillary sinus height compared to those aged 12 to 17 years. Furthermore, the height and depth of the maxillary sinus were also significantly greater in the 18 years and older group compared to the 6 to 11-year group. However, the width of the maxillary sinus was notably smaller in the 18 years and older age group.

Moreover, Kitchlu et al.[18] conducted a study utilizing CT images from 118 patients aged between 20 and 50 years. The participants were categorized into three distinct age groups: 20 to 30 years, 31 to 40 years, and 41 to 50 years. The researchers measured the length, width, and height of the maxillary sinus, with volume calculated using a specific equation. Notably, in the 20 to 30 years age group, the width of the right maxillary sinus was greater than that of the other groups. The most significant increase in maxillary sinus volume was recorded in the 21 to 25 years age group, with a general increase in sinus volume observed from ages 20 to 30 and again in the 51 to 60 years age group, followed by a decline thereafter. Additionally, the height of the left maxillary sinus in the 31 to 40 years age group showed significant results. In the 41 to 50 years age group, both the right and left maxillary sinus heights were significant. Furthermore, it was noted that beyond the age of 40 years, there was a reduction in the dimensions of the maxillary sinus.

Also, Tiwari et al.[19] conducted a study involving 90 CT scans, comprising 49 males and 41 females, aged between 18 and 55 years. The participants were divided into three distinct age categories: 18 to 25, 26 to 40, and 41 to 55 years. Measurements were obtained from both 2D and 3D reconstructed images of the maxillary sinuses. Linear measurements included anteroposterior (AP), superioinferior (SI), and mediolateral (ML) dimensions, as well as the distance between the right and left maxillary sinuses, assessed in both coronal and sagittal planes. The volume of the sinuses was calculated using a specific formula. The results indicated that the third age group (41–55 years) exhibited the highest mean values, while the lowest values were recorded in the 18 to 25 age group.

On the other hand, Naduvinkeri et al.[20] performed a study involving 300 lateral cephalograms from patients aged 11 to 40 years. The participants were categorized into three age groups: 11-20 years, 21-30 years, and 31-40 years. The researchers assessed the maxillary sinus by measuring its height, width, and the index, which is the ratio of the sinus width to its height. Their findings indicated that the maxillary sinus index was the most effective parameter for age estimation across all age groups.

The observed inconsistencies may be attributed to variations in patient demographics, sample sizes, radiographic methodologies, and analytical approaches. Additionally, the specific measurement techniques and the software employed could potentially influence the outcomes. [15]

In conclusion, the results in our study revealed that there was a Weak Negative correlation of age with volume, height, width, and depth. Also the older age group exhibited a statistically significant reduction in mean height, width, depth, and volume compared to the younger age group. Moreover, the volume had the largest correlation with age.

Conclusion

The application of the maxillary sinus for age estimation has limited accuracy; however, the volume of the maxillary sinus serves as the most reliable indicator for age estimation in human identification.

Funding

This research did not receive any specific grant.

Data availability

All data included in this study are available from the corresponding author upon request.

Ethics approval

Ethical approval was granted from the research Ethical Committee at Faulty of Dentistry, Ain-Shams University. (Approval number FDASU_Rec EM012105).

Informed consent

For this type of study, formal consent is not required.

Competing interests

The authors declare that they have no competing interests.

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