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Computed Tomography- Based Maxillary Sinus Morphometry: A Tool for Gender Differentiation in Libyan Population

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Abstract

Introduction: In forensic contexts, gender identification is a multifaceted process that involves examining various anatomical characteristics to determine an individual's gender. Recent advancements in medical imaging techniques, such as computed tomography (CT) scans have provided researchers and healthcare professionals with more detailed insights into anatomical differences between genders such as the dimensions of paranasal sinuses.

Aim: This study aimed to compare the maxillary sinus (MS) dimensions between genders in a Libyan sample using CT scans.

Materials and methods: One hundred consecutive Libyan patients, comprising 50 women and 50 men, were included in the study. The Width, height, and length were determined based on CT images. Additionally, the perimeter, area, and volume of the MS were calculated mathematically. The collected data analyzed to compare the MS parameters between genders in both sides. Statistical significance was accepted at $p<0.05$.

Results: Statistically we found that the length, width and length of the MS were significantly different between male & female in both sides, while there was no significant difference in case of sinus area and volume. The accuracy level for correctly classifying gender based on width of right MS was 91.8%, demonstrating strong predictive power of this parameter. The result showed also that 94 % of males and 90% of females were sexed correctly with an overall accuracy of 92%.

Conclusion: This study highlights the importance of understanding sinus morphology in forensic anthropology for gender determination.

Keywords: Maxillary Sinus; Computed Tomography; Morphometry; Volume; Gender And Forensic Medicine.

1. Introduction

Determining gender is a crucial aspect of identifying an unknown individual, aiding in accurate diagnoses. When the skeleton is intact, gender determination can reach 100% accuracy. If both the skull and pelvis are available, gender can be discerned based on morphological features with around 98% accuracy (1).

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In many instances, the collected bones are fragmented or mixed, especially in catastrophic events. Despite this, studies note that zygomatic bones and the maxillary sinus (MS) often remain preserved, even in destructive scenarios like fire or animal predation (2,3).

The complexity of the maxillofacial region poses challenges for diagnosis and treatment, with the MS extending over maxillary molar roots leading to a 60% underdiagnosis rate for missed apical lesions (4). The MS, being the largest paranasal sinus, plays roles in reducing skull weight and enhancing voice resonance (5).

Paranasal sinus development starts prenatally, becoming visible on radiographs around 5 months after birth and completing pneumatization around age 20 (3,5). Thus, the subjects aged 20 or above were included in this study.

The fully developed maxillary sinus has a pyramid-like structure, connected to the nasal wall, zygomatic process, orbital floor, and alveolar process of the maxilla. Drainage occurs into the middle meatus (6).

Computed Tomography (CT) scans offer precise evaluations of paranasal sinuses, including sinus pneumatization. CT scans provide cross-sectional and three-dimensional information, commonly available in hospitals (7).

Considering this background, the current study aimed to assess MS morphometry for gender identification of gender on CT images of a Benghazi population sample.

2. Materials and methods

2.1. Patient selection

Patients were selected from those undergoing CT scans at Dar Al-Asheaa center between December 2023 and February 2024 for this retrospective study. Pre-operative clinical notes were examined to gather patient demographic information and the indication for the CT scan. Inclusion criteria comprised patients aged between 20 and 65 years. The exclusion criteria encompassed patients with prior maxillary surgery, maxillofacial deformities, or a history of extracted maxillary molars, as MS pneumatization might be influenced. Additionally, patients with pathological changes in the target area were excluded. Fourteen patients were further excluded due to incomplete or unclear documentation, as well as distortion or deflection in the radiographic images.

One hundred consecutive Libyan patients, comprising 50 women and 50 men, were included in the study. Two independent reviewers, unaware of the subjects' details, conducted multiple measurement sessions for various parameters of the maxillary sinus at weekly intervals to mitigate memory bias.

2.2. Compliance with ethical standards

As this was a retrospective imaging study, it did not entail the use of identifying information for the included patients. Therefore, no written or verbal consent was sought from patients or their guardians. The study adhered to the ethical standards set by the research ethics committee in Benghazi, Libya.

2.3. Scanning and analysis procedures

Axial and coronal images were acquired using a 64-multidetector row CT scanner (Philips Brilliance CT 64, Philips Healthcare, Netherlands). Patients were positioned in the supine position for all scans. Imaging parameters were set to a tube voltage of 120 kV and a current-time product of 175 mAs. The tube rotation time was 0.75 s with a pitch of 0.89. The CT scan had an acquisition collimation of 64 × 0.625 mm, and the field of view ranged from 250 to 300 mm in diameter. Viewing and measuring was by image system.

The present study utilized plain CT scans exclusively. Contrast-enhanced CT scans displaying signs of pathology were deliberately excluded from the analysis.

The objective of this study was to assess the width, length, height, area, and volume of the maxillary sinus. Additionally, gender comparisons and differences between the left and right sides were analyzed.

2.4. Measurements

All included subjects underwent measurements of MS parameters on both sides. Width, height, and length were determined based on reference points (see table 1). Additionally, mathematical formulae were employed to calculate the perimeter, area, and volume of the MS.

Table 1 The different parameters of the maxillary sinus

The parameter	The unit	The reference point
The width (W)	mm	As measured from the outermost point of the lateral wall to the medial wall.
The height (H)	mm	As the distance between the roof and lowermost point of the floor of the sinus.
The length (L)	mm	The longest distance between the anterior and posterior wall.
The area (A)	mm^2	Area=Length× width
The perimeter (P)	mm	Perimeter= 2 x length + 2 x width.
The volume (v)	mm^3	Volume = length x width x height x1/2

Mean value of each linear measurement was then calculated. Width and length distances were measured on the axial section [Fig1&2], whereas, the height distances were measured on coronal cross-section [Fig2]. Area, perimeter and volume were calculated from the previous linear measurements.

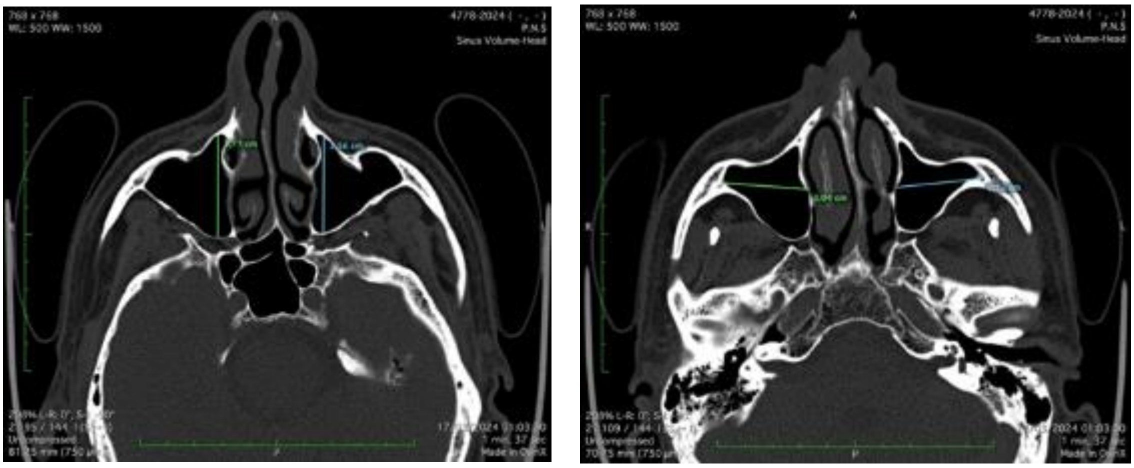

Figure 1 Measurement of the length and the width of maxillary sinus on the axial section

Figure 2 Measurement of the height of maxillary sinus on the coronal section.

2.5. Statistical analysis

The collected data underwent processing, computation, and analysis utilizing SPSS software version 26. Mean and standard deviation values were calculated for each parameter. The Kolmogorov-Smirnov test was used to verify the normality of the variables. Contingency tables were drawn up using the Chi-squared test and t-student test to compare categorical the maxillary sinus parameters between genders in both sides. The level of correlation between the quantitative variables was studied using the Pearson Correlation Coefficient test. All of the divergences in which the p value was $p<0.05$. were considered to be statistically significant (0.001 for the Pearson correlation coefficient).

3. Results

3.1. Comparison of different parameters of right MS between males and females

The difference in mean value of the different parameters with respect to right MS between males and females was found to be statistically significant ($p<0.05$) except for Right MS Perimeter and volume (table 2).

Table 2 The right MS parameters (width, length, height, area, perimeter, volume) were measured and compared between males and females. The sign * denotes statistically significant difference

Parameter	Gender	No.	Mean	S.D	Mean differences	P value
Right Maxillary Sinus Width (mm)	Male	50	26.93	1.18	2.84	<0.001*
	Female	50	24.08	0.692		
Right Maxillary Sinus Length (mm)	Male	50	36.35	1.03	-2.48	<0.001*
	Female	50	38.83	1.34		
Right Maxillary Sinus Height (mm)	Male	50	36.23	1.36	1.12	<0.001*
	Female	50	35.11	1.11		
Right Maxillary Sinus Area (mm^2)	Male	50	96.65	1.72	3.52	<0.001*
	Female	50	93.13	1.52		
Right Maxillary Sinus Perimeter (mm)	Male	50	127.36	1.58	0.420	0.151
	Female	50	126.94	1.31		
Right Maxillary Sinus Volume (mm^3)	Male	50	165.46	1.64	-0.092	0.766
	Female	50	165.5580	1.45		

3.2. Comparison of different parameters left MS between males and females

The difference in mean left maxillary sinus parameters between males and females was found to be statistically significant ($p<0.05$) except for left MS Perimeter and volume. (Table 3).

Table 3 The left MS parameters (width, length, height, area, perimeter, volume) were measured and compared between males and females. The sign * denotes statistically significant difference

Parameter	Gender	No.	Mean	S.D	Mean differences	P value
Left Maxillary Sinus Width (mm)	Male	50	29.02	1.4	4.306	<0.001*
	Female	50	24.72	0.96		
left Maxillary Sinus Length (mm)	Male	50	37.89	1.06	-2.12	<0.001*
	Female	50	40.01	1.22		
left Maxillary Sinus Height (mm)	Male	50	37.67	1.56	1.59	<0.001*
	Female	50	36.07	0.73		

left Maxillary Sinus Area (mm^2)	Male	50	97.82	1.23	3.11	<0.001*
	Female	50	94.7	1.06		
left Maxillary Sinus Perimeter (mm)	Male	50	128.29	1.71	0.41	0.222
	Female	50	127.88	1.62		
left Maxillary Sinus Volume (mm^3)	Male	50	169.7	2.35	-0.40	0.370
	Female	50	170.1	2.09		

3.3. Odds ratio and accuracy level for each parameter in determining gender

Tests of Normality using Kolmogorov-Smirnov and Shapiro-Wilk revealed that the data didn't follow normal distribution, therefore logistical regression model was used to test Odds ratio and accuracy level for each parameter in determining the gender.

Chi-square analysis of the significance difference between the various measurements were performed and the correlation with gender and side were analyzed (Table 4).

Table 4 Odds ratio and accuracy level for each parameter in determining gender

Parameter	Male		Female		Chi sq	P value	Correctly Classified %
	ODDS	CI 95%	ODDS	CI 95%			
RW	0.033	(0.07-0.165)	30.24	(6.05-151.2)	103.31	<0.001	91.8%
RL	4.048	(2.45-6.68)	0.247	(0.15-0.41)	64.9	<0.001	80%
RH	0.478	(0.328-0.698)	2.091	(1.43-3.05)	18.86	<0.001	60%
RA	0.343	(0.23-0.51)	2.91	(1.98-4.28)	68.65	<0.001	86%
RP	0.817	(0.62-1.08)	1.224	(0.93-1.61)	2.1	0.151	54%
RV	1.04	(0.81-1.34)	0.961	(0.74-1.24)	0.091	0.764	49%
LW	0.068	(0.015-0.30)	14.74	(3.33-65.22)	114.45	<0.001	95%
LL	4.62	(2.58-8.27)	0.216	(0.121-0.39)	59.42	<0.001	82%
LH	0.35	(0.22-0.54)	2.88	(1.84-4.52)	35.35	<0.001	74%
LA	0.078	(0.024-0.26)	12.82	(3.87-42.48)	95.61	< 0.001	92%
LP	0.861	(0.68-1.09)	1.16	(0.91-1.47)	1.52	0.220	51%
LV	1.086	(0.91-1.29)	0.921	(0.771-1.10)	0.824	0.366	51%

RW has a significantly higher odds ratio for determining gender compared to other parameters. The results show that the odds ratio for determining gender based on RW is 0.033 for males and 30.24 for females, with a chi-square value of 103.31, indicating a significant relationship between RW and gender. The accuracy level for correctly classifying gender based on RW is 91.8%, demonstrating strong predictive power of this parameter.

Similarly, the odds ratio for determining gender based on LW is 0.068 for males and 14.74 for females, with a chi-square value of 114.45, indicating a significant relationship between LW and gender (fig. 3) The accuracy level for correctly classifying gender based on LW is 89%, demonstrating strong predictive power of this parameter.

The study also found other parameters such as RL, RH, RA, LL, LH, and LA show significant differences between males and females in determining gender. The other parameters such as RV, RP, LV, and LP have the lowest and non-significant prediction for the gender.

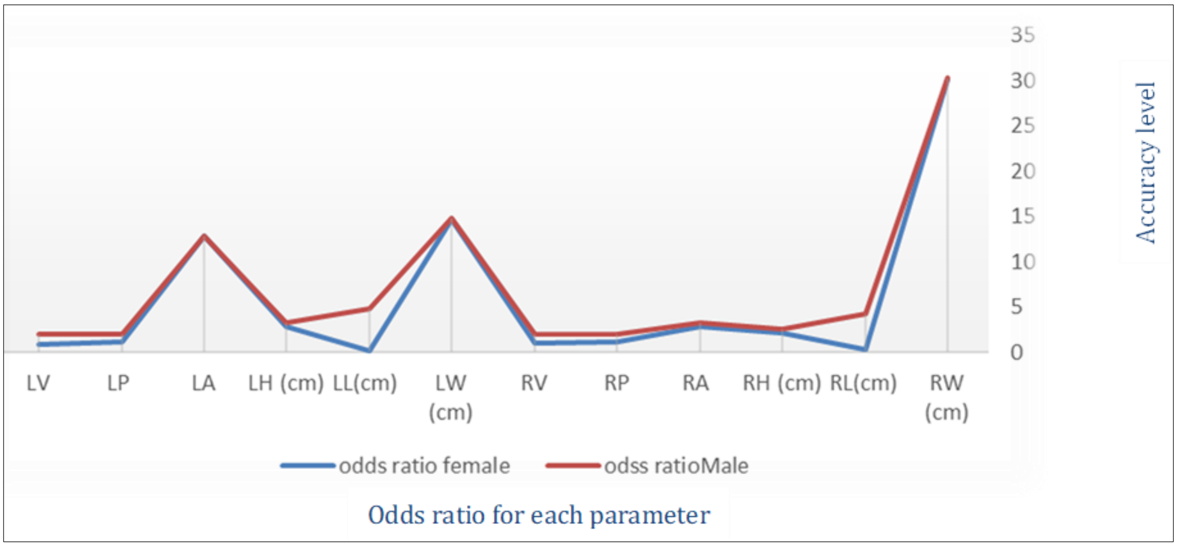

Figure 3 Odds ratio and accuracy level for each parameter in predicting gender

The final result of the analysis shows that 94 % of males (47) and 90% of females (45) were sexed correctly. The given parameters when used to identify the gender of a sample will be able to provide results with an accuracy of 92% (Table5).

Table 5 Accuracy of the final model in determining gender

Actual gender	Predicted GENDER		% Correctly Classified
	female	male	
female	45	5	% 92
Male	3	47	
Total	48	52	

3.4. The sensitivity and specificity values for all variables

Table 6 The sensitivity and specificity values for all variables

PARAMETER	AUC	P Value	Sensitivity	Specificity	Z value
RW	0.983	<0.001	100%	85%	-0.5
RL	0.025	<0.001	30%	16%	-0.43
RH	0.718	<0.001	52%	82%	0.28
RA	0.928	<0.001	92%	80%	-0.16
RP	0.572	0.213	46%	28%	0.21
RV	0.473	0.637	44%	37.9%	0.091
LW	0.993	<0.001	94%	96%	-0.21
LL	0.099	<0.001	76%	11%	-1.16
LH	0.799	<0.001	80%	68%	-0.39
LA	0.973	<0.001	98%	84%	-0.21
LP	0.572	0.215	44%	72%	0.63
LV	0.460	0.488	56%	44%	0.11

Generally, the values of the different dimensions of both the right and left maxillary sinuses show a range of sensitivities and specificities, where most of the parameters are having higher predictive values. The overall accuracy of the measurements represented by the AUC values are shown in the table (6).

The results demonstrated that the RW of less than 24.56 cm with a high AUC value of 0.983 (the sensitivity of 100% and specificity of 85%), similarly LW less than 26.35 cm, with AUC 0.993 (The sensitivity of 94%, and specificity of 96%), ($p<0.0015$) are the most accurate predictors of the gender. In contrast, the Right and left MS Length Height and volume showed lower predictive power, with less AUC values.

4. Discussion

Radiology is essential in providing precise dimensions for objects, it facilitates the application of specific formulas to determine gender (5,8). This CT-based study evaluates the different dimensions of the MS as the CT imaging offers accurate measurements for MSs, which cannot be obtained through other mean.

Considering the impact of developmental diseases, chronic infections, and craniofacial malformation on the MS, the study excluded patients with related disease conditions. Furthermore, extracting maxillary molars could lead to increased sinus pneumatization, bringing the remaining root apices closer to the sinus floor (9).

Various studies using CT scans reported significant individual variability in MS dimensions, which may be influenced by factors such as human variability and pneumatization triggers, even within the same individual (10,11,12, 13). For instance, Ariji et al. (14) reported an average width of 27 mm and a length of 35.6 mm, which aligns with our measurements.

In the current study, it was found that the dimensions of the MS were statistically different between sexes. Males generally exhibited larger absolute dimensions for MS height, width, and surface area compared to females. Additionally, females tended to have a taller MS in the anterior-to-posterior direction for a given MS size. However, there was no significant difference in term of volume and perimeter based on gender.

In the literature, there has been a longstanding debate regarding sex-based differences in the MS. Many authors observed that in males, the MSs tend to have a larger volume, wider width, and greater height compared to females (2, 9,11,15,16,17). Sharma SK et al conducted a study using CT scans, noted statistically significant differences in sinus length and volume, they concluded that the observed difference in MS dimensions between genders may be linked to physiological changes in nasal cavity size according to respiratory needs (18). Although a study by Sahlstrand (9) described larger sinus sizes in females.

In the current study, the mean volume was 16.75 cm^3 for males and 17.78 cm^3 for females. Consistent with other studies (9, 14, 17,13,19, 20) we did not find significant differences in sinus volume based on the sex of the patients.

The uneven values of the volumes of the previously evaluated MSs may be attributed to differences in the structure of the samples. These findings highlight the complexity of using generalizations based on gender, as while men are typically larger than women, it's possible to encounter a strong, tall female and, conversely, a short, slender male (18).

These disparities may also arise from the use of different measurement techniques. Automated evaluation of sinus volume using specific software programs can provide reliable volumetric measurements. However, Giacomini et al. (20) compared automated segmentation to manual segmentation carried out by an experienced radiologist using a standardized procedure, revealing similar average for sinus volume, with a high correlation between the measurements obtained by both methods. The availability of software enables more precise 3D volumetric measurements. Nevertheless, for medical purposes, using linear and bidimensional measurements offers a more cost-effective and simpler alternative (10).

While the MS is largely bilaterally symmetrical, significant individual differences exist in the size and shape of both sides (21). The current study demonstrated statistically significant differences in the length, height and surface area of the MS in both sides. Same findings have been reported previously in the literature (19). However, Gulec et al. (22) reported no significant differences in average volume between the right and left MSs. This observation has also been supported by other studies (15,13,20), where no significant differences in volume in both sides within the same individual.

One potential explanation for the left-right differences in MS dimensions could be variations in the eruption timing of permanent teeth between the both sides (23). Although no previous study has explored the impact of permanent tooth eruption on maxillary sinus morphology, this is a topic worth investigating in future research.

Our study analyzed the accuracy level for each parameter in determining gender. Specifically, the RW emerged as the best discriminant parameter, with an overall accuracy of 91.8%, followed closely by the left width at 89%. These findings are in consistent with previous results (18). Many studies have identified different parameters as the best discriminants for gender identification **(**Refer to Table 7).

Table 7 Different parameters of the MS identified as gender determiners in the literature

Authors	**Maxillary sinus**	**Accuracy (%)**
Urooge et al. (9)	left width	60
Uthman et al. (8)	height	71.6
Attia et al. (24)	right height	69.9
Ahmed et al. (25)	left width	61.3
Sharma et al. (18)	Length	69.81
Otsuki et al. (23)	Left height	68%
Dangore-Khasbage (26)	Left sinus angle	78%
Amin & Hasan (12)	Sinus height	71%

The analytical approach used in this study showed that about 94% of males and 90% of females were sexed correctly with an overall accuracy of 92%. These results outperformed previous studies using similar parameters. For example, Dangore-Khasbage (26) reported an overall accuracy rate of 86% for sex determination using MS, with 85% accuracy in males and 87% in females. Prabhat et al. (27) and Bangi et al. (28) also achieved comparable accuracy rates of 83.3% and 88%, respectively.

However, some studies reported accuracy rate below 70%s (3, 9, 18, ,19). Uthman et al. (8) reported a correct sexing rate of 74.4% for male sinuses and 73.3% for female sinuses, with an overall accuracy of 73.9%. Additionally, Fernandes (13) obtained an accuracy rate of 79.0% for gender determination using MS.

Our study's higher prediction accuracy compared to previous studies may be attributed to various factors, including differences in race, genetic and environmental influences which include body stature, height, osteoclastic and osteoblastic activity, pneumatization processes of the sinus, and previous infections.

Fernandes (13) established the role of the MS in ethnic classification, noting significantly larger antral volumes in European crania compared to Zulu crania, with European sinuses also wider than Zulu sinuses. Butaric et al. (29) further supported these findings, indicating lower sinus volume in Peruvian samples compared to Australian samples. Similarly, Suhhyun (30) found that individuals of Asian ancestry tend to have larger MSs than those of African or European ancestry. Consequently, the measurement obtained in the current study is warranted, considering the observed differences among ethnic groups.

This study marks the first report highlighting the significance of maxillary sinus parameters in sexual determination within the Libyan population. Such studies provide baseline values for assessing sexual dimorphism and can guide implantation and surgical maxillary approaches based on morphometric dimensions of the sinus.

One of the limitations of this study is the small sample size which is a result of rigorous inclusion criteria. Future gender difference studies should consider larger sample sizes from diverse geographical areas.

While CT imaging is valuable for 3D sinus evaluations, its cost and radiation risks remain drawbacks. Cone beam CT imaging offers a simpler, low-radiation, and cost-effective alternative.

Although our study highlighted the right sinus width as a significant parameter for sex differences, it's advisable to conduct a more thorough assessment of the skull which may involve other anatomical landmarks such as head circumference, nasal cavity dimensions, the width between malar bones, and corners of the eye.

5. Conclusion

Male group exhibited statistically significant higher values for MS width, length, and height. Notably, the width of the right MS demonstrated a high accuracy level for classifying gender, highlighting the strong predictive power of this parameter. The overall accuracy of using the MS for gender identification was 92%. We propose that measurements of the MS can serve as effective tools for gender determination in forensic anthropology when the intact skeleton is not available.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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