ORIGINAL ARTICLE

Morphometry of the Maxillary Sinus and its Role in Sex Determination in Delta State Nigeria: Retrospective CT Study

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Abstract :

The morphometric parameters of the maxillary sinus are important in the forensic identification of unknown human skulls. This study aimed at determining the accuracy of using the dimensions of the maxillary sinus in sex determination. Skull Computed Tomography images of 292 adult patients, stored in the Radiology Department of a teaching hospital in Nigeria were retrospectively used to measure the dimensions of the maxillary sinus after obtaining the institution's approval. Using the Statistical Package for Social Sciences Version 23, the side and gender comparisons were evaluated using student's t-test while the correlation between the metric parameters was determined using Pearson's test. P-value was considered significant at <0.05. Discriminant function analysis was used to evaluate the accuracy of using the dimensions for sex prediction. The dimensions of the maxillary sinus were significantly larger in males than in females (p<0.05) but lacked significant association with age (p>0.05). The left maxillary sinus height was the best sex discriminating variable (238,81.5%). The accuracy of correct sex prediction increased when all the dimensions of the right (240,82.2%), left (243,83.2%) or both maxillary sinuses (258,88.4%) were used. In conclusion, the MS dimensions may be used for sex determination with acceptable accuracy in the studied population.

Keywords : Maxillary sinus; Morphometry; Sex; Prediction.

Introduction :

Forensic identification of unknown human remains is important in mass disasters and criminal investigations.[1] This process entails the determination of gender as a vital initial step followed by the estimation of age and race.[2] Human identification can be achieved using fingerprints, deoxyribonucleic acid (DNA) analysis, and anthropological methods. However, in the absence of soft tissue due to extreme decomposition and incineration, it is difficult to use fingerprints and DNA for identification.[1,2] Furthermore, despite being the most accurate method, DNA analysis is time-consuming and expensive. Conversely, linear anthropometric parameters are more reliable, simple, and inexpensive.[3] Sex can be determined from the morphological features and anthropometric parameters of bones such as the skull, pelvis, and long bones.[1,2] Mass disasters such as fire incidents and explosions often result in severe skeletal fragmentation or burns. Therefore, only the bones that resist crushing or disfigurement are available for forensic identification.[4] Paranasal sinuses especially the frontal and maxillary sinuses are recovered intact hence, useful in the identification of fragmented, decomposed or burnt remains.[3]

The maxillary sinus (MS), is the largest paranasal sinus located within the body of the maxilla, and drains into the nasal cavity via the middle meatus.[5] It is the earliest sinus to develop during the 10th week of intrauterine life as a mucosal invagination from the lateral nasal wall.[6] At birth, it is a shallow fluid-filled sac located inferomedial to the orbital floor. After birth, it continues to pneumatize into the developing alveolar ridge and this concurs with the eruption of the permanent teeth.[2] The eruption of the third molar is completed by 20 years of age and this is associated with the attainment of the adult size of the maxillary sinus and the end of its pneumatization.[7]

The shape, size and position of the MS shows side, individual, gender, population, ethnic, and racial differences due to the different degrees of sinus pneumatisation and variant facial morphology.[2,8,9] Previous studies have documented sexual dimorphism in the dimensions of the maxillary sinuses, mainly attributed to the sex differences in the mid-face region, body stature, genetics and nutrition.[4,7,10]

Using the Discriminant Function Analysis (DFA), previous studies have reported varying accuracies of correct sex prediction using MS dimensions.[5,7,11,12] Computed Tomography (CT) is considered the gold standard method for accurate assessment of craniofacial bones and complex anatomy of the paranasal sinuses.[2] The CT measurements of the MS have been reported to be reliable in gender determination during forensic identification.[4,11] Data on the accuracy of using the CT measurements of the MS for sex determination in Delta State, Nigeria is scarce. This study therefore aimed at evaluating the accuracy of correct sex prediction using the morphometric parameters of the MS measured on skull CT images of adult Nigerians.

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Article History
DOR : 04.08.22; DOA : 05.12.22

Materials and Methods :

The retrospective cross-sectional design was adopted in this study. Brain CT images of patients referred to the Radiology Department of a Teaching Hospital in Delta State, Nigeria within a duration of 5 years (1st of June 2015 to 30th of June 2020) were used. The indications for brain CT were suspected intracranial thrombus, hemorrhage or tumours and chronic headache. The images were accessed in the Picture Archiving and Communications Systems (PACS) after obtaining ethical approval from the Hospital (Reference number: EREC/PAN/2020/030/0371). A 64 slice CT machine (Toshiba Aquillon, 2009, Japan) was used to acquire these images at 120kV and 300mA and in 3mm thick axial slices. These slices were later reformatted to obtain sagittal and coronal sections. We included brain CT images of patients aged 20 years and above because the maxillary sinus reaches its adult size at 20 years.[1] Any image lacking age and gender specifications or images of patients aged below 20 years were excluded from the study. Moreover, images with fractures of the facial bones, previous sinus surgery, features suggestive of sinonasal pathology such as mucosal thickening, tumors, and polyps, as well as congenital craniofacial anomalies were excluded from this study. Poor quality images with artefacts and poor patient positioning were also barred. Therefore, 292 brain CT images which fit our inclusion criteria were used in this study.

Using bone window, the maxillary sinuses were identified on axial, coronal and sagittal sections. The sinus dimensions were obtained using digital calipers in PACS, calibrated in centimeters (cm). The anteroposterior (AP) dimension of the MS was defined by the longest distance between the most anterior point to the most posterior point of the medial wall in the axial section. The width of the sinus was determined as the longest distance from the medial to lateral walls of the sinus on axial view (Fig. 1A). The height was measured as the longest distance from the lowest point of the sinus floor to the highest point of the sinus roof on a coronal reformatted image (Fig. 1B).[13] The total distance across both maxillary sinuses was measured as the distance between the outermost lateral points of the right and left MS on an axial section (Fig. 1C).[14] The inter-maxillary distance was the longest distance between the medial walls of the right and left MS on axial images (Fig. 1C).[13] The anterolateral angle was measured as the angle between the anterior and lateral walls of the MS using a digital protractor calibrated in degrees (Fig. 1D).[4]

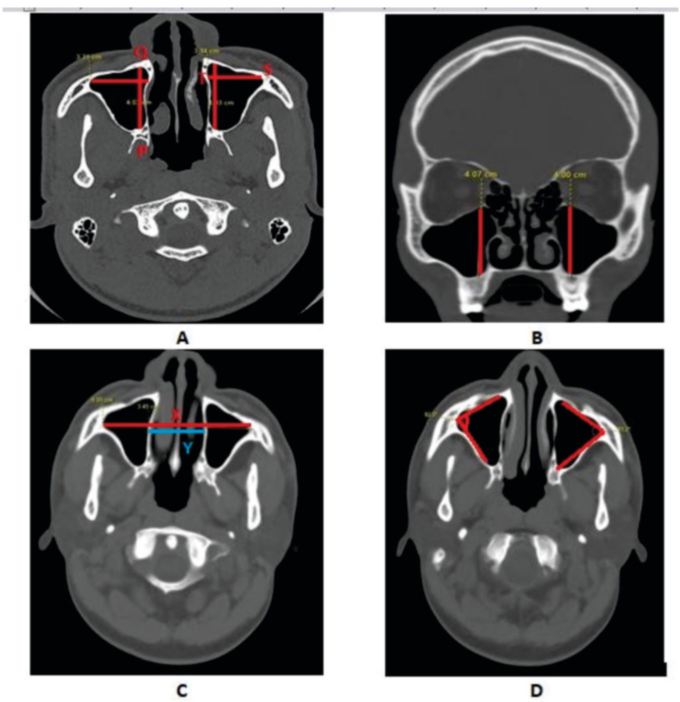

Figure 1. Computed tomographic images showing the measurement of maxillary sinus dimensions A. Width(TS) and depth (PQ) B. Height C. Intermaxillary distance (Y) and total distance across both maxillary sinuses (X) D. Anterolateral angle

The volume of the MS was determined using the geometric calculation of the volume of a pyramid; the product of the surface area of the base (depth x width) and a third of the height.[15] The MS index was calculated as the ratio of maxillary width to height.[16] Statistical Package for Social Sciences (SPSS) Version 23; IBM® Armonk, New York was used to analyze data in this study. The gender and side differences in the metric variables were evaluated using independent t-test and paired t-test respectively. Correlation between the parameters was probed using Person's correlation test. A p-value level of <0.05 was considered significant. Discriminant function analysis (DFA) was used to determine the accuracy for correct sex prediction.[17]

Results :

The MS of 177 males (60.6%) and 115 females (39.4%) were evaluated in this study. These patients had an age range of 20-99 years and an average age of 51.47 ± 17.22 years. The average depth, width and height of the MS in the studied population were 3.97 ± 2.10 cm, 2.97 ± 0.57 cm and 3.59 ± 0.55 cm respectively. The mean MS index and volume were 0.83 ± 0.17 and 13.84 ± 6.07 cm^3 correspondingly. These metric parameters were significantly larger on the right than the left MS ($P<0.05$) (Table 1). Furthermore, they were significantly larger in males than in females ($P<0.05$) (Table 2). The mean anterolateral angle of the MS was 79.46 ± 7.89^0 and also showed significant side and gender differences ($P<0.05$) (Tables 1 and 2). The inter-maxillary distance and the total distance between the outermost points of the MS showed a significant association with gender ($P<0.05$) (Table 2).

The metric parameters of the MS did not show any significant association with age ($p>0.05$) (Table 3). The right MS depth, width, height and volume showed significant positive correlation with corresponding metric variables on the left MS (Table 3). There was a significant positive correlation between the depth and width, depth and height as well as width and height of the MS. Moreover, the volume of the MS showed significant positive correlation with the depth, width and height ($p<0.05$) (Table 3). From the univariate analysis, the height of the left MS was the best sex discriminating variable (238, 81.5%) followed by the height of the right MS and depth of the left MS (79.8% each) (Table 4). From the multivariate analysis, the calculated coefficients and constants are shown on Table 5. The variables of the left MS provided a slightly higher overall accuracy (243, 83.2%) of sex prediction compared to the combined use of all the right MS dimensions (240, 82.2%). Using the metric parameters of both right and left MS showed the highest accuracy (258, 88.4%) (Table 6).

Discussion :

The average depth, height and width of the MS in this study were larger than the dimensions documented in several previous studies.[4-6,10] On the contrary, some studies documented smaller MS dimensions compared to our findings.[6,16] The volume of the MS was higher than the reports by AbdulHameed et al.[5] In contrast, the volume herein was lower than the findings by Ozdikici[18] who used the cavalieri method, and Dhakar et al.[19] and Hadj et al.[6] who used a different formula of calculating the MS volume (product of craniocaudal, anteroposterior and transverse diameters). The MS index was lower than the reports of Khaitan et al.[20] and Velpula et al.[16] mainly because the maxillary sinuses they evaluated had larger widths and smaller heights compared to our findings.

The population differences in the mean dimensions and volume of the MS may be attributed to genetic, racial, ethnic, environmental and geographical factors.[9] The differences in the methodology used in the studies may also explain the variances in the findings. For instance, the study design, sample size, gender and age distribution, imaging modality, CT slice/view, and landmarks used in measuring the parameters vary in different studies.[21] The right MS had significantly larger dimensions and volume than the left MS. This significant asymmetry could perhaps be ascribed to the independent embryonic development and pneumatisation of each sinus. On the contrary, other scholars did not observe any significant side differences in the MS parameters.[5,6,18,19]

We observed sexual dimorphism in the MS dimensions and volume and these were larger in males. This is consistent with the findings by Sathawane et al.,[7] Hadj et al.,[6] and Supraja et al.[10] On the contrary, Hadhoud and Abdelhakim[2] did not observe any significant gender differences in the MS parameters among the Egyptians studied. Consistent with Khaitan et al.,[20] the MS index was significantly larger in females than in males. This contrasted with Velpula et al.[16] who documented significantly larger MS index in males compared to females. The sexual variations in the MS variables have been ascribed to sex differences in body stature, skeletal size, physique, genetics, nutrition, and caloric intake.[4,7] The larger MS volumes in males are due to their bigger body size, robust cranial features, as well as higher respiratory needs which are associated with physiological changes in the nasal shape and size and subsequently the maxillary sinuses.[2,6,13] On the other hand, females have smaller MS because they retain pedomorphic traits throughout their development.[4] Therefore, the sexual dimorphism in the morphometric parameters of the MS in our population indicates their potential use in gender determination where other methods of sex determination are inconclusive in forensic and criminal investigations.

Consistent with Etemadi et al. (2017), the MS parameters did not show any significant association with age. This could possibly be due to the inclusion of subjects aged 20 years and above. By the age of 20 years, the MS attains its adult size after the full development of permanent teeth and the eruption of the 3rd molar.[16] Its dimensions remain stable beyond the second decade of life.[3,7] Additionally, this result could be associated with the unequal distribution of subjects in the different age-groups. Our findings suggest that the MS dimensions cannot be used in the estimation of age in the studied population. On the contrary, Netharaa et al.[22] reported an increase in the area of the MS with age. These authors associated this with the increasing bone resorption that occur with aging. The discrepancies in the findings could be due to the differences in osteoclastic activity, and pneumatization patterns of the MS as well as presence or absence of teeth which vary with age.[9]

We report larger inter-maxillary distance and total distance across both MS compared to the findings by Eldahab and Dakhli[13] and Uthman et al.[14] respectively. These scholars similarly observed significant gender differences in these distances. Netharaa et al.[22] documented a larger average distance measured across the maxillary sinuses on 20 postero-anterior skull radiographs and this could probably be due to the inherent magnification on radiographs. The mean anterolateral angle of the MS in our study was larger than in the Indians studied by Dangore-Khasbage and Bhowate.[4] Contrary to the reports of these authors, the angle was significantly larger on the right MS than the left. Congruent with our findings, Dangore-Khasbage and Bhowate[4] reported significant gender differences in the anterolateral angle of the MS and attributed this to the sex variations in the mid-facial contour and size of the MS. They concluded that the anterolateral angle of the MS can be used in gender determination. The significant positive correlation between dimensions of the MS implies that an increase in the dimension of the MS on one side is associated with a corresponding increase in the contralateral MS. Similarly, the dimensions and volume of the same sinus may be used to estimate each other. These significant associations may be applicable in forensic investigations.

Parallel to the reports of Uthman et al.,[14] the height of the left MS was the best sex discriminating variable in this study (81.5%). Similarly, according to Sathawane et al.[7] and Deshpande et al.,[1] the heights of the MS were the best variables for sex prediction. Other MS parameters had varied accuracies in different populations. For instance, the left AP dimension showed a sex predictive accuracy of 56.2% while the left CC (height) dimension had an accuracy of 55.4% among Nigerians studied by AbdulHameed et al.[5] According to Ravali[23] and Patel et al.,[8] the width of the left MS was the best sex discriminating parameter. The MS volume and intermaxillary distance were the best for sex grouping in Egypt. Their combination yielded an overall accuracy of 70%.[13] The MS index has also shown a high accuracy (72%-79%) for correct sex allocation in some populations.[16,20]

The accuracy of using the dimensions of the right and left MS for sex determination was 82.2% and 83.2% respectively. These were higher than the percentage accuracies reported by Kandel et al.[11] and lower than those by Fatima et al.[12] Consistent with our findings, these scholars documented higher accuracies of sex prediction using the left MS dimensions compared to the right

Table 1: The side differences in the mean dimensions of the maxillary sinuses.

Variables	Right	Left	Average	P value
Depth (cm)	4.09±2.91	3.84±0.59	3.97±2.10	0.044*
Width (cm)	2.99±0.58	2.96±0.56	2.97±0.57	0.010*
Height (cm)	3.60±0.53	3.57±0.57	3.59±0.55	0.041*
MS index	0.83±0.56	0.83±0.57	0.83±0.56	0.102
Volume (cm3)	14.32±8.02	13.37±4.11	13.84±6.07	0.001*
Anterolateral angle (o)	80.46±7.93	78.5±7.84	79.46±7.89	0.001*

* P considered significant at <0.05

Table 2: Gender differences in the morphometry of the MS.

Morphometric parameter	Side	Female	Males	P value
AP/ depth (cm)	R	3.72±2.84	4.33±2.94	0.001*
	L	3.43±0.54	4.11±0.46	0.001*
	Av	3.58±2.04	4.22±2.10	0.001*
Width (cm)	R	2.77±0.41	3.14±0.63	0.001*
	L	2.75±0.40	3.10±0.60	0.001*
	Av	2.76±0.40	3.12±0.61	0.001*
Height (cm)	R	3.20±0.31	3.87±0.47	0.001*
	L	3.15±0.30	3.85±0.53	0.001*
	Av	3.18±0.31	3.86±0.50	0.001*
Volume (cm3)	R	10.98±7.67	17.66±8.36	0.001*
	L	10.00±2.55	16.74±5.65	0.001*
	Av	10.49±5.72	17.20±7.00	0.001*
Maxillary sinus index	R	0.87±0.17	0.82±0.19	0.001*
	L	0.88±0.15	0.82±1.78	0.001*
	AV	0.88±0.16	0.82±0.18	0.001*
Inter-maxillary distance (cm)		3.39±0.77	3.56±0.57	0.001*
Total maxillary distance (cm)		8.35±1.14	9.05±1.20	0.001*
Anterolateral angle	R	75.51±7.67	85.40±8.22	0.001*
	L	73.45±6.28	83.55±9.40	0.001*
	Av	74.48±6.43	84.47±8.81	0.001*

*Statistical significance was considered at P<0.05, R-Right, L- left, AV- Average

Table 3: Correlation between variables of the maxillary sinus.

A. Correlation between the mean metric parameters of the maxillary sinus

Variables		Age	Depth	Width	Height	Volume
Age	r	1	0.143	0.287	0.201	0.116
	p value		0.072	0.104	0.251	0.082
Depth	r	0.143	1	0.123*	0.107*	0.241*
	p value	0.072		0.003	0.010	0.012
Width	r	0.287	0.123*	1	0.248*	0.146*
	p value	0.104	0.003		0.001	0.004
Height	r	0.201	0.107*	0.248*	1	0.293*
	p value	0.251	0.010	0.001		0.031
Volume	r	0.116	0.241*	0.146*	0.293*	1
	P value	0.082	0.012	0.004	0.031	

B. Correlation between corresponding variables of the right and left maxillary sinus.

Variable	Correlation coefficient	P-value
Depth	0.137	0.020*
Width	0.855	0.001*
Height	0.857	0.001*
Volume	0.017	0.004*

r- correlation coefficient, * P considered significant at <0.05

Table 4. Univariate discriminant function analysis of orbital measurements.

Metric parameter	Con-stant	Canonical Coefficients	Group Centroids		SP	Accuracy (%)		
			Male	Female		Male	Female	Average
Right MS								
Height	-8.683	2.410	0.644	-0.991	-0.174	137 (77.4)	96 (83.5)	233 (79.8)
Width	-5.396	1.805	0.266	-0.409	-0.072	140 (79.1)	65 (56.5)	205 (70.2)
Depth	-1.411	0.345	0.084	-0.129	-0.023	135 (76.3)	67 (58.3)	202 (69.2)
MS Index	-4.712	5.756	0.015	-0.023	0.004	140 (79.1)	73 (63.5)	213 (72.9)
Left MS								
Height	-7.863	2.202	0.615	-0.947	-0.166	141 (79.7)	97 (84.3)	238 (81.5)
Width	-5.605	1.893	0.269	-0.414	-0.073	136 (76.8)	62 (53.9)	198 (67.8)
Depth	-7.804	2.031	0.555	-0.854	-0.150	155 (87.6)	78 (67.8)	233 (79.8)
MS Index	-4.949	5.719	0.078	-0.120	-0.021	143 (80.8)	77 (67)	220 (75.3)

MS- maxillary sinus SP-sectioning point

Table 5: Multivariate analysis of the maxillary sinus variables.

Variables	Canonical coefficient	Constant	Centroids		Eigen value	Wilk's Lambda
			Males	Females		
Right MS						
Depth	0.040	-10.192	0.703	-1.082	0.744	0.573
Width	0.684					
Height	2.215					
Left MS						
Depth	1.307	-10.067	0.766	-1.179	0.884	0.531
Width	-0.161					
Height	1.547					
Combined MS variables						
Right MS depth	0.018	-11.180	0.822	-1.265	1.018	0.496
Left MS depth	1.189					
Right MS width	0.037					
Left MS width	-0.051					
Right MS height	1.387					
Left MS height	0.443					

Table 6: Accuracy of correct sex prediction from the multivariate analysis of the maxillary sinus dimensions.

Combined Dimensions	Original Accuracy (%)			Accuracy after cross-validation (%)		
	Males	Females	Average	Males	Female	Average
Right MS	140 (79.1)	100 (87.0)	240 (82.2)	140 (79.1)	100 (87.0)	240 (82.2)
Left MS	145 (81.9)	98 (85.2)	243 (83.2)	145 (81.9)	98 (85.2)	243 (83.2)
Both right and left MS	154 (87.0)	104 (90.4)	258 (88.4)	153 (86.4)	102 (88.7)	255 (87.3)

MS. Congruent with Uthman et al.,[14] and Fatima et al.,[12] the accuracy further increased with the combination of the dimensions bilaterally (88.4%). On the other hand, Hadhoud and Abdelhakim[2] used multiple regression analysis and observed a poor discriminate power (18%) of the MS dimensions in gender prediction, and concluded that these variables are not validated in sex determination in the studied Egyptian population.

The variation in the accuracy rates of sex estimation and discrepancies in the best sex discriminating variables may be due to geographical diversity or population differences based on ethnicity and race.[12] Other factors contributing to these dissimilarities include varied radiographic methods, technique, landmarks, metric parameters, sample size and statistical analysis used in sex prediction.[13] The allocation of gender in females with larger MS dimensions or males with smaller MS dimensions may be also be false.[12]

Conclusion :

The metric parameters of the MS show sexual dimorphism with the height of the MS being the most accurate predictor of sex. Therefore, the MS may be used for sex determination in our studied population.

Limitations of the Study : This study was limited by the small sample size owing to its retrospective nature and the use of images from a single radiological unit. The unequal distribution of patients in the different age-groups as well as the inclusion of edentulous patients could also have influenced the findings.

Recommendations : We recommend that a multi-centered study can be conducted in the region in order to obtain a larger sample size with equal distribution based on gender and age. Moreover, the MS morphometry in dentulous and edentate subjects can also be compared.

Acknowledgements: We extend our appreciation to the staff at the Radiology Department of Delta State University Teaching Hospital who provided technical help during the period of data collection.

Conflict of Interest: Nil

Source of Funding: Nil

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