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Original Article

Sex and Age Estimation by measuring Maxillary Sinus Dimensions and Bizygomatic Distance using Cone Beam Computed Tomography: Retrospective Study

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Abstract

Aim: The aim of this study is to identify sex and estimate age by measuring the maxillary sinus dimensions and bizygomatic distance using CBCT. **Subjects and Methods:** Using 180 CBCT scans 90 males and 90 females divided into 3 age groups; Group I: 18-29 years, Group II: 30-41 years, and Group III: 42-60 years; medio-lateral (ML), superior-inferior (SI), anteroposterior (AP), antero-lateral angle (ALA), volume (Vol.) of both right (R) and left (L) maxillary sinuses (MS), intermaxillary distance (IMD), and bizygomatic distance (BZD) were measured and compared. Discriminant function analysis and linear regression analysis were performed for sex identification and age estimation respectively. **Results:** A significantly higher mean values of right and left ML in males than females (p=0.001) and (p=0.002) respectively. Mean values of AP, SI, Vol. of both sides and BZD were significantly higher in males (p=0.000). ALA revealed high insignificant mean values in females. IMD revealed high insignificant mean value in males. No significant difference between age groups regarding MS measurements, ALAR and BZD. But ALAL and IMD showed a significantly lower value in Group I in comparison to Group II and III (p=0.018) (p=0.000) respectively. In terms of discriminative ability, SIR had the highest overall sex prediction accuracy 69.44%. Linear regression analysis for age prediction revealed that IMD had the highest overall prediction $R^2 = 0.143$. **Conclusions:** The use of maxillary sinus dimensions and BZD may be valuable for sex determination. Conversely, these variables revealed poor results for age estimation.

Keywords: Bizygomatic distance, Cone Beam Computed Tomography, Maxillary sinus, Sex determination, Forensic identification

Introduction

Identification process objectives to discriminate similar characteristics in missing individuals (Gamba et al. 2017). In forensic sciences, the process of human identification remains one of the most relevant aspects as it is the first step in forensic dentistry when using bone remains of disappeared individuals (Gamba et al. 2017; Santiago de Mendonça 2021). Sex determination and age estimation is considered as an important problem in the identification process; because most Skeletal remnants that are conventionally used for identification, such as skull bones, pelvis and long bones, are frequently recovered in an incomplete or fragmented state (Jehan et al. 2014). Thus, it has become important to use denser bones that are often recovered intact. It has been reported that zygoma and maxillary sinus remain intact although other bones may be badly disfigured (Chaurasia and Katheriya 2016; Patil et al. 2022).

Until now, the most reliable identification means include fingerprints, dental comparison, and biological procedures such as DNA profiling (Hemanthakumar et al. 2022). However, sometimes these means cannot be applied, when the remains are burnt or decomposed, the DNA is destroyed or when there are no previous dental records (Soares et al. 2020; Patil et al. 2022).

Several radiographic techniques, such as conventional radiography, computed tomography (CT), and cone-beam computed tomography (CBCT), have been used to assess various parameters for determining an individual's sex and age as they are very simple, cheap, and take less time compared with conventional biochemical and histopathological methods (Patil et al. 2022; Tiwari et al. 2023). CBCT is a modality with high dimensional accuracy in measuring craniofacial structures. It offers several advantages for postmortem forensic imaging including good resolution, relatively low cost, and simplicity (Deshpande et al. 2022). Systematic reviews by Sridhar et al. (2023) and Sampaio-Oliveira (2024) concluded that more studies should be carried out to estimate sex including different populations to realize the diversity and their consistency. As well, Lima et al. (2020) recommended further researches regarding age prediction due to the deficiency of studies in this point. Thus, the aim of this study is sex determination and age estimation by measuring the maxillary sinus dimensions and bizygomatic distance using CBCT.

Subjects and Methods

This retrospective cross-sectional study was approved by the Ethics committee of the faculty of Dentistry Cairo university with code number 25423. From archives of the Oral and Maxillofacial Radiology Department, 180 CBCT scans (90 males and 90 females) were collected, Images of FOV 20 x 20 cm and with exposure parameters; 400 µm voxel size, 90 kVp and 8 mA for 13.5 sec were acquired with a CBCT scanner Planmeca Promax imaging system (Planmeca Oy, Helsinki, Finland). DICOM images were then exported to computer running windows 10, and then viewed using Plameca romaxies viewer software version 6.1.0.997. Study subjects were then divided into 3 groups according age; Group I: 18-29 years, Group II: 30-41 years, and Group III: 42-60 years. Each group included 60 patients (30 males and 30 females)

Inclusion criteria:

- Age of Subjects were ranging from 18 to 60 years.

- Subjects with fully erupted maxillary teeth with/without the third molars.

- Scans are devoid of any developmental anomalies, pathologies and fractures involving the maxillary sinus, zygomatic arch, and zygomatic bone.

- Ideal CBCT images with optimum diagnostic quality, clearly showing the maxillary sinuses, zygomatic arch, and zygomatic bone and free of artefacts.

Exclusion criteria

- Radiographic evidence of the developmental anomalies, pathology and fractures involving the maxillary sinus, zygomatic arch, and zygomatic bone.

- Subjects with missing or partially erupted maxillary teeth other than the third molars.

- CBCT images with poor diagnostic quality and images that do not clearly show the maxillary sinuses, zygomatic bone, and zygomatic arch.

The CBCT images were assessed by two qualified oral and maxillofacial radiologists. Axial and coronal cuts were used to measure linear/angle measurements. Parameters/ variables included in this study were; the medio-lateral dimension or width (ML), the superio-inferior dimension or height (SI), the antero-posterior dimension or length (AP), antero-lateral angle (ALA), volume (Vol.) of both right (R) and left (L) maxillary sinuses (MS), intermaxillary distance (IMD), and bizygomatic distance (BZD). Before CBCT scan, the patient was prepared so, the mid-sagittal plane is perpendicular to floor and the Frankfort plane (FP) is parallel to floor. Similarly, before measurement procedure, the images were checked and adjusted to be ensure that these orientations had the same relation with the horizontal plane. In order to improve the accuracy of measurements, the linear/angular measurements were repeated using many slices to detect the slice of the largest dimension and this was the dimension used in the statistical analysis.

The variables are measured as following:

1. The width (ML) of each MS (MLR and MLL) was measured as the maximum distance between medial and lateral walls of the maxillary sinus on the axial cut (Fig. 1).

2. The length (AP) of each MS (APR and APL) was measured as the maximum distance between anterior and posterior walls of the maxillary sinus on the axial cut (Fig. 2).

3. The height (SI) of each MS (SIR and SIL) was measured as the maximum distance between superior and inferior walls of maxillary sinus on coronal cut (Fig. 3).

4. The Intermaxillary distance (IMD) was measured on axial cut by measuring the maximum distance between medial walls of right and left maxillary sinuses (Fig. 4).

5. Bizygomatic distance (BZD) was measured on axial view by measuring the maximum distance between the most prominent points of zygomatic arches on both right and left sides (Fig. 5).

6. Anterolateral angle (ALA) of each MS (ALAR and ALAL) was measured as the maximum angle between the anterior and lateral walls of maxillary sinus (Fig. 6).

7. The volume of maxillary sinuses of both sides (Vol.R and Vol.L) was calculated using previously measured dimensions of MS, according to the following formula V= (height (SI) × length (AP) × width (ML) × 0.5).

To assess the reliability, the measurements were repeated twice by the same operator with 2-week interval between data recording phases to assess the significance of any errors during the measurement process. The results of the first and the second series of measurements were compared for intra-observer agreement. For statistical analysis, the first series of measurements was used. Then, to assess the inter-observer agreement, 100 CBCT scans were randomly selected and measured again by another observer. Both observers were blinded to patients' data during the measuring process.

Statistical analysis

Statistical analysis was made with R statistical analysis software version 4.4. for windows. Intraclass Correlation Coefficient (ICC) was used to assess both inter-rater reliability (two-way random effects model) and intra-rater reliability (one-way random effects model). Values were presented as mean, standard deviation (SD), confidence intervals and range. Normality was confirmed by viewing the distribution and using Shapiro-Wilk's test. For parametric data, ANOVA test was used to compare between different age groups, followed by Bonferroni's post hoc test for multiple pairwise comparisons. sexes were compared used independent t test. The strength of the linear relationship between two variables was measures by Pearson correlation test. It has a value between -1 to 1, with a value of -1 meaning a total negative linear correlation, 0 being no correlation, and + 1 meaning a total positive correlation. The strength of the correlation is interpreted as follows: The absolute value of r: .00-.19 "very weak"; .20-.39 "weak"; .40-.59 "moderate"; .60-.79 "strong"; .80-1.0 "very strong".

Linear discriminant function analysis was used to evaluate the ability of different variables to discriminate sex, while linear regression models were utilized for age estimation. Variance homogeneity was evaluated using Box's M test for discriminant function analysis and Levene's test for regression models. For multivariable models, multicollinearity was assessed using the Variance Inflation Factor (VIF), with variables showing VIF values greater than five excluded from the models. The reported accuracies and performance metrics in different models were obtained using leave-one-out cross-validation across the entire dataset. This method maximizes the use of available data by using each observation as a test case once, providing an unbiased estimate of model performance and ensuring a comprehensive assessment of the model's robustness. Regarding linear regression models, R2 measures the proportion of variance in the dependent variable that can be predicted from the independent variables. It takes values from 0 (i.e., the model does not explain any variability of response) to 1 (i.e., the model explains all variability of response). The significance level for all tests was set at p<0.05.

Results

For inter-rater reliability values ranged from 0.821 (good agreement) to 0.987 (excellent agreement) with overall agreement being excellent (ICC=0.995). For intra-rater reliability, agreement for all measurements was excellent (ICC>0.9).

I-Comparison between males and females (Table 1) (Fig. 7)

A significantly higher mean values of ML were recorded in males (28.28±4.2 and 29.28±4.8) than females (25.88±4.88 and 26.86±5.5), (p=0.001 and p=0.002) of right and left sides respectively. Mean values of AP were significantly higher in males (39.15±3.42 and 39.33±3.77) than females (35.91±4.94 and 36.28± 4.45) (p=0.000 and p=0.000) of right and left sides respectively. Likewise, mean values of SI were significantly higher in males (37.93±5.64 and 37.62±6.1), in comparison to females (33.09±5.66 and 33.23± 5.13) (p=0.000 and p=0.000) of right and left sides respectively. Maxillary sinus volume showed significantly higher mean values in males (21.64±7.04 cm3 and 22.29±7.35 cm3), in comparison to females (16.17±6.73 cm3 and 16.92±6.53 cm3) (p=0.000 and p=0.000) of right and left sides respectively.

Regarding ALA, a non-significant higher mean value was recorded in females (81.39±8.59 and 79.05±8.29) than males (79.38±7.78 and 78.6± 7.76) (p=0.102 and p=0.708) of right and left sides respectively. IMD revealed higher mean value in males (35.52±3.65), in comparison to females (34.53±3.09) nevertheless, this difference was insignificant (p=0.051). BZD recorded a significantly higher mean value in males (98.08±5.05), in comparison to females (92.58±7.36), (p=0.000).

II-Comparison between age groups (Table 2, 3) (Fig. 8)

The study included three age groups 60 subjects in each of them, Group I (18-29 years), Group II (30-41 years), and Group III (42-60 years). No significant difference was revealed between age groups regarding ML, AP, SI and Vol. of right and left sides. Likewise, ALAR showed no significant difference between age groups. Concerning ALAL, the highest mean value was observed in Group III (80.2±7.94), followed by Group II (79.8±8.22), with no significant difference between these 2 groups, however with a significantly lower value recorded in Group I (76.43±7.44) (p=0.018).

IMD of Group III presented the highest mean value (36.51±2.87), followed by Group II (35.37±3.44), with no significant difference between these 2 groups, however with a significantly lower value recorded in Group I (33.15±3.05) (p=0.000). Whereas, the mean value of BZD displayed no significant difference between age groups.

III- Correlation between different variables

IMD showed a weak positive (r=0.298) statistically significant correlation with BZD (p=0.000) and very weak positive non-statistically significant with maxillary sinus volume (r=0.099, r=0.065 for the right and left side respectively). Likewise, BZD correlation with maxillary sinus volume was weak positive (r=0.368, r=0.381 for the right and left side respectively) but it was statistically significant (p=0.000). The volume of maxillary sinus of both sides showed a very strong positive statistically significant correlation (r=0.845) (p=0.000).

IV- Discriminant function analysis for sex prediction

Univariable discriminant function analyses are presented in (Table 4). All models demonstrated statistically significant Wilks' Lambda values p<0.001, with both sexes having centroids with opposite signs, confirming the predictors' discriminatory effectiveness. In terms of discriminative ability, the model of SIR had the highest overall prediction with accuracy of

69.44%, sensitivity (accurate male predictions) of 69.66% and specificity (accurate female predictions) of 70.0%. Multivariant overall model, including all variables, revealed higher values with accuracy of 73.89%, sensitivity of 75.29% and specificity of 76.67% (Table 5).

Multivariable discriminant function analyses are presented in (Table 5) for each age group to predict sex. All models similarly showed statistically significant Wilks' Lambda values p<0.001. The oldest age group model (42-60 years) revealed the best discriminative ability for sex prediction with accuracy of 77.61%, a sensitivity of 78.79% and a specificity of 78.79%. The models of younger age groups (30-41 and 18-29 years) displayed accuracies of 74.07% and 69.49% respectively.

V - Linear regression analysis for age prediction

Univariable regression analyses are presented in (Table 6). IMD, BZD, ALAR and ALAL significantly predicted age with p-values (<0.001, 0.024, 0.029 and 0.011 respectively) while, IMD was the variable showed the highest overall prediction as it recorded the highest value of R^2 = 0.143 but it still a low value. Multivariable regression analyses are presented in (Table 7), showed that the model could estimate the age in males more than females R^2 = 0.232 and 0.111 respectively. Overall model, including all variables, revealed a low value of R^2= 0.188.

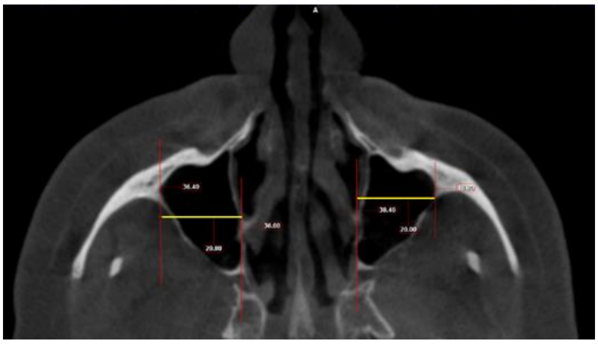

Figure 1: Axial view of CBCT showing the measurement of the maxillary sinus width (ML) as the maximum distance between medial and lateral walls of the sinus.

Figure 2: Axial view of CBCT showing the measurement of the maxillary sinus length (AP) as the maximum distance between anterior and posterior walls of the sinus.

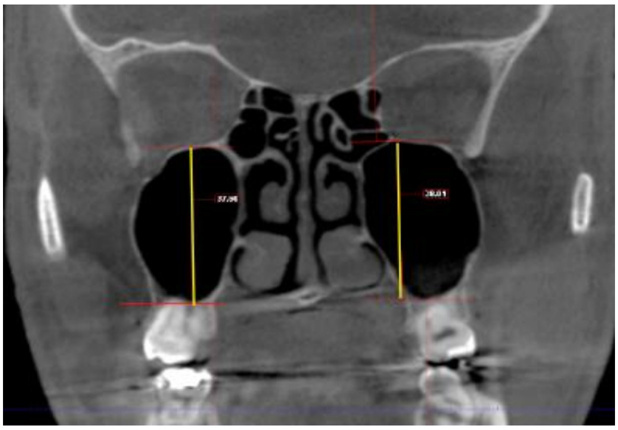

Figure 3: Coronal view of CBCT showing the measurement of the maxillary sinus height (SI) as the maximum distance between superior and inferior walls of the sinus.

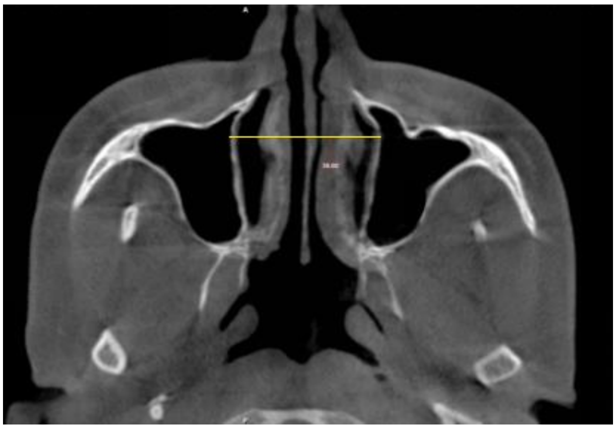

Figure 4: Axial view of CBCT showing the measurement of intermaxillary distance (IMD) as the maximum distance between medial walls of right and left maxillary sinuses.

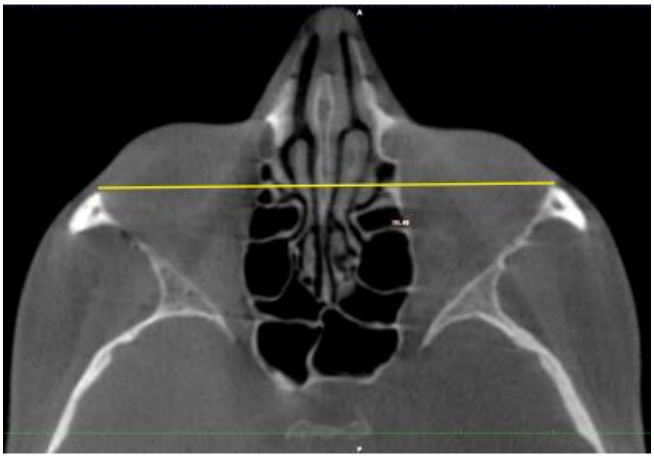

Figure 5: Axial view of CBCT showing the measurement of bizygomatic distance (BZD) as the maximum distance between the most prominent points on the right and left zygomatic arches.

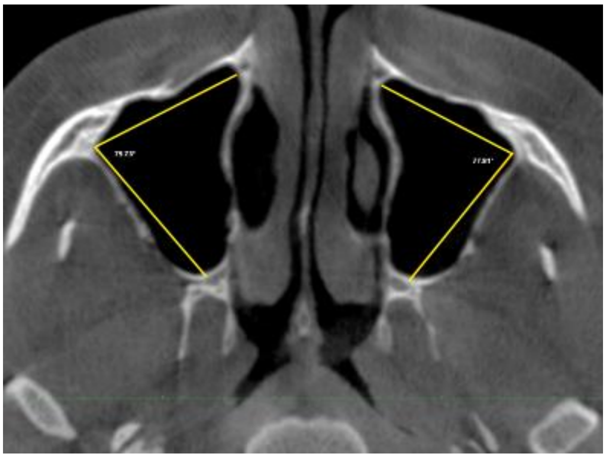

Figure 6: Axial view of CBCT showing the measurement of the antero-lateral angle (ALA) as the angle between the anterior and lateral walls of the maxillary sinus.

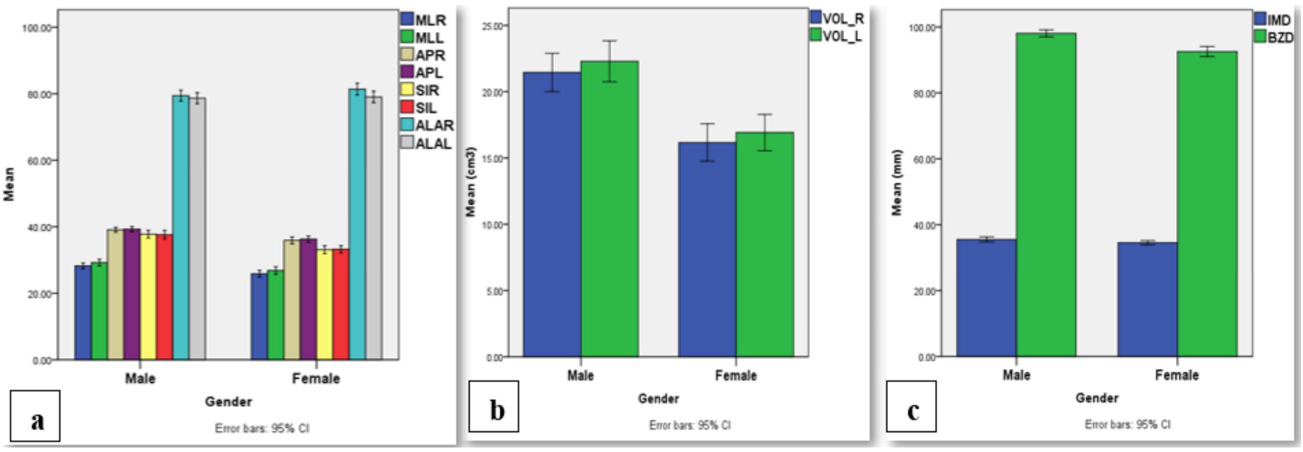

Figure 7: Bar chart illustrating **a)** Mean value of ML, AP, SI (mm) and ALA (°); **b)** Mean value of maxillary sinus volume (cm^3); **c)** Mean value of IMD and BZD (mm) in the right and left sides in both sexes.

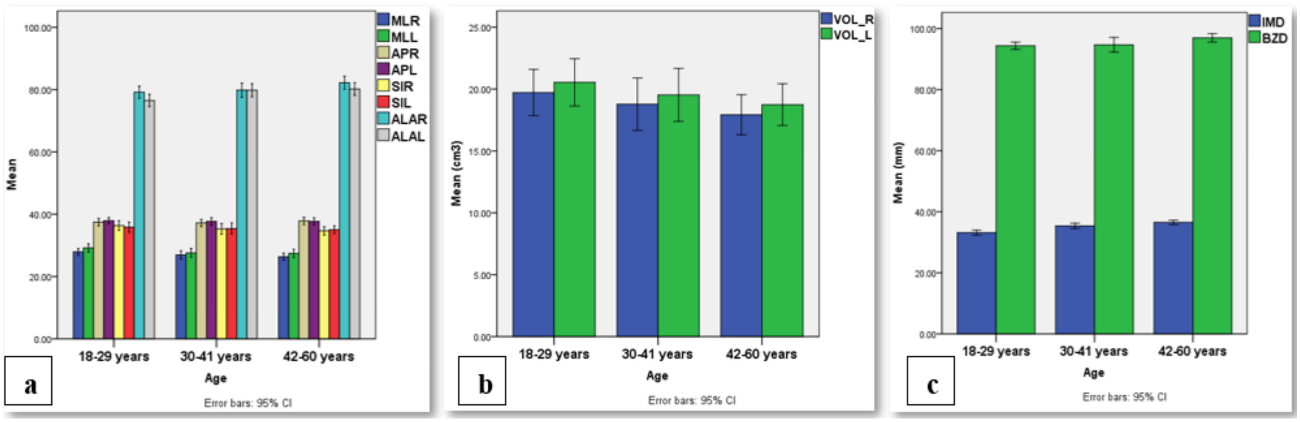

Figure 8: Bar chart illustrating **a)** Mean value of ML, AP, SI (mm) and ALA (°); **b)** Mean value of maxillary sinus volume (cm3); **c)** Mean value of IMD and BZD (mm) in the right and left sides in different age groups.

Table (1): Comparison between males and females (Independent t test)

Variable	Gender	Mean	Std. Dev	Difference				P value
				Difference	Std error of difference	C.I. lower	C.I. upper	
MLR	Male Female	28.28 25.88	4.20 4.88	2.41	.68	1.07	3.75	0.001*
MLL	Male Female	29.28 26.86	4.80 5.50	2.42	.77	.90	3.94	0.002*
APR	Male Female	39.15 35.91	3.42 4.94	3.25	.63	2.00	4.50	0.000*
APL	Male Female	39.33 36.28	3.77 4.45	3.05	.61	1.84	4.26	0.000*
SIR	Male Female	37.93 33.09	5.64 5.66	4.84	.84	3.18	6.50	0.000*
SIL	Male Female	37.62 33.23	6.10 5.13	4.40	.84	2.73	6.06	0.000*
ALAR	Male Female	79.38 81.39	7.78 8.59	-2.01	1.22	-4.42	.40	0.102 ns
ALAL	Male Female	78.60 79.05	7.76 8.29	-.45	1.20	-2.81	1.91	0.708 ns
Vol.R (cm3)	Male Female	21.64 16.17	7.04 6.73	5.47	1.03	3.44	7.49	0.000*
Vol.L (cm3)	Male Female	22.29 16.92	7.35 6.53	5.38	1.04	3.33	7.43	0.000*
IMD	Male Female	35.52 34.53	3.65 3.09	.99	.50	-.01	1.98	0.051 ns
BZD	Male Female	98.08 92.58	5.05 7.36	5.51	.94	3.65	7.36	0.000*

Significance level p≤0.05, *; significant, ns; non-significant, R=right, L=left

Table (2): Comparison between different age groups; ML, AP, SI, ALA (ANOVA test)

Variable	Age Group	N	Mean	Std. Dev	95% Confidence Interval for Mean		Min	Max	F	P value
					Lower Bound	Upper Bound				
MLR	18-29 y	60	27.98	4.08	26.92	29.05	15.00	35.00	1.891	0.154 ns
	30-41 y	60	26.95	5.32	25.58	28.31	12.00	37.00		
	42-60 y	60	26.33	4.52	25.16	27.50	12.80	37.50		
	Total	180	27.08	4.70	26.39	27.77	12.00	37.50		
MLL	18-29 y	60	29.26	5.03	27.95	30.57	15.00	38.00	2.248	0.109 ns
	30-41 y	60	27.58	5.48	26.17	28.98	13.60	38.40		
	42-60 y	60	27.42	5.23	26.07	28.77	17.00	39.00		
	Total	180	28.07	5.29	27.30	28.85	13.60	39.00		
APR	18-29 y	60	37.57	4.61	36.37	38.77	23.00	45.60	.307	0.736 ns
	30-41 y	60	37.19	4.53	36.03	38.35	20.80	45.50		
	42-60 y	60	37.84	4.53	36.67	39.01	23.00	46.40		
	Total	180	37.53	4.54	36.86	38.20	20.80	46.40		
APL	18-29 y	60	38.06	3.97	37.02	39.09	29.00	46.00	.140	0.869 ns
	30-41 y	60	37.68	4.66	36.49	38.87	22.00	45.50		
	42-60 y	60	37.69	4.55	36.51	38.87	24.50	44.80		
	Total	180	37.81	4.39	37.16	38.45	22.00	46.00		
SIR	18-29 y	60	36.61	6.22	34.99	38.23	23.00	52.00	1.561	0.213 ns
	30-41 y	60	35.28	6.82	33.53	37.02	20.00	47.90		
	42-60 y	60	34.67	5.18	33.33	36.01	19.60	46.00		
	Total	180	35.51	6.13	34.61	36.41	19.60	52.00		
SIL	18-29 y	60	35.82	6.24	34.18	37.46	20.00	49.00	.256	0.775 ns
	30-41 y	60	35.41	6.92	33.64	37.18	21.20	49.00		
	42-60 y	60	35.02	4.81	33.78	36.26	26.00	45.00		
	Total	180	35.41	6.03	34.52	36.30	20.00	49.00		
ALAR	18-29 y	60	79.09	7.40	77.16	81.02	67.00	94.17	2.394	0.094 ns
	30-41 y	60	79.83	8.91	77.55	82.11	59.50	105.50		
	42-60 y	60	82.22	8.10	80.13	84.31	66.70	100.00		
	Total	180	80.38	8.23	79.17	81.59	59.50	105.50		
ALAL	18-29 y	60	76.43 y	7.44	74.49	78.37	63.00	98.60	4.112	0.018*
	30-41 y	60	79.80 x	8.22	77.70	81.91	62.00	99.70		
	42-60 y	60	80.20x	7.94	78.14	82.25	67.80	99.00		
	Total	180	78.83	8.01	77.65	80.01	62.00	99.70		

Significance level $p \leq 0.05$, *significant, ns-non-significant, R=right, L=left; Post hoc test: means sharing the same superscript letter are not significantly different

Table (3): Comparison between different age groups; Volume, IMD, BZD (ANOVA test).

Variable	Age Group	N	Mean	Std. Dev	95% Confidence Interval for Mean		Min	Max	F	P value
					Lower Bound	Upper Bound				
Vol.R (cm3)	18-29 y	60	20.03	7.45	18.09	21.97	5.26	38.18	1.226	0.296 ns
	30-41 y	60	18.77	8.29	16.65	20.89	3.26	37.88		
	42-60 y	60	17.93	6.26	16.31	19.54	4.24	32.17		
	Total	180	18.90	7.39	17.81	19.99	3.26	38.18		
Vol.L (cm3)	18-29 y	60	20.54	7.28	18.62	22.45	4.35	37.45	.862	0.424 ns
	30-41 y	60	19.53	8.36	17.39	21.67	4.99	34.90		
	42-60 y	60	18.74	6.55	17.05	20.43	6.79	30.80		
	Total	180	19.59	7.44	18.49	20.69	4.35	37.45		
IMD	18-29 y	60	33.15b	3.05	32.36	33.95	27.00	41.00	17.693	0.000*
	30-41 y	60	35.37a	3.44	34.49	36.26	27.00	47.60		
	42-60 y	60	36.51a	2.87	35.77	37.25	30.00	44.00		
	Total	180	35.03	3.41	34.52	35.53	27.00	47.60		
BZD	18-29 y	60	94.36	4.46	93.20	95.52	86.80	106.00	2.556	0.081 ns
	30-41 y	60	94.68	9.47	92.25	97.10	39.00	106.00		
	42-60 y	60	96.94	5.34	95.56	98.32	85.60	106.00		
	Total	180	95.33	6.87	94.32	96.34	39.00	106.00		

Significance level p≤0.05, *significant, ns-non-significant, R=right, L=left; Post hoc test: means sharing the same superscript letter are not significantly different

Table (4): Univariable discriminant function analysis for sex identification.

Variable	Coefficient	Fisher's linear DF		Centroids		Accuracy of cross-validated predictions (%)			Cut off	
		Male	Female	Male	Female	Sensitivity	Specificity	Accuracy	Cut off value	Cut off score
Constant **MLR**	-5.94 0.22	-19.97 1.36	-16.83 1.25	0.264	-0.264	58.06%	56.67%	58.33%	22.62	-0.98
Constant **MLL**	-5.44 0.19	-16.78 1.10	-14.23 1.01	0.235	-0.235	56.67%	56.67%	56.67%	27.20	-0.17
Constant **APR**	-8.84 0.24	-43.18 2.17	-36.42 1.99	0.382	-0.382	66.23%	71.11%	63.89%	38.65	0.26
Constant **APL**	-9.17 0.24	-46.20 2.31	-39.42 2.13	0.370	-0.370	69.05%	71.11%	67.78%	40.20	0.58
Constant **SIR**	-6.29 0.18	-23.23 1.19	-17.85 1.04	0.428	-0.428	69.66%	70.00%	69.44%	35.25	-0.05
Constant **SIL**	-6.24 0.18	-22.70 1.17	-17.73 1.03	0.398	-0.398	65.22%	64.44%	65.56%	37.22	0.30
Constant **BZD**	-15.10 0.16	-121.37 2.46	-108.21 2.32	0.436	-0.436	67.71%	65.56%	68.89%	97.30	0.31
Constant **IMD**	-10.36 0.30	-55.85 3.11	-52.82 3.02	0.146	-0.146	54.55%	50.00%	55.00%	37.30	0.67
Constant **ALAR**	-9.81 0.12	-47.63 1.18	-50.04 1.21	-0.123	0.123	51.85%	56.67%	51.67%	92.47	1.48
Constant **ALAL**	-9.81 0.12	-48.58 1.22	-49.12 1.23	-0.028	0.028	47.67%	50.00%	47.78%	76.20	-0.33
Constant **Vol.R (cm3)**	-2.75 0.15	-5.63 0.46	-3.54 0.34	0.397	-0.397	63.00%	58.89%	64.44%	14.92	-0.58
Constant **Vol.L (cm3)**	-2.87 0.14	-5.65 0.45	-3.59 0.34	0.370	-0.370	62.24%	58.89%	63.33%	23.02	0.50

DF: discriminant function.

Table (5): Multivariable discriminant function analysis of each age group and all variables to predict sex.

Age Group	Variable	Coefficient	Fisher's linear DF		Centroids		Accuracy of cross-validated predictions (%)			Cut off score
			Male	Female	Male	Female	Sensitivity	Specificity	Accuracy	
18-29 years	Constant	12.87	-323.41	-313.83	-0.367	0.380	70.37%	73.33%	69.49%	0.04
	IMD	0.21	0.29	0.45						
	BZD	0.26	5.11	4.92						
	ALAR	0.08	0.97	1.03						
	ALAL	0.02	0.93	0.92						
30-41 years	Constant	13.39	-205.18	-188.72	-0.615	-0.615	76.00%	77.78%	74.07%	-0.35
	IMD	0.16	4.37	4.18						
	BZD	0.09	1.08	0.98						
	ALAR	0.01	0.92	0.93						
	ALAL	0.01	0.87	0.87						
42-60 years	Constant	27.80	-533.98	-491.21	-0.780	0.757	78.79%	78.79%	77.61%	0.15
	APR	0.13	3.75	3.54						
	APL	0.01	0.52	0.54						
	IMD	0.05	4.48	4.41						
	BZD	0.19	5.00	4.71						
	ALAR	0.03	0.46	0.51						
	ALAL	0.07	2.47	2.35						
Overall	Constant	16.64	-270.75	-252.37	-0.552	0.552	75.29%	76.67%	73.89%	-0.10
	APR	0.08	1.56	1.48						
	APL	0.07	1.56	1.48						
	IMD	0.03	2.51	2.48						
	BZD	0.10	1.65	1.54						
	ALAR	0.03	0.93	0.97						
	ALAL	0.04	1.18	1.14						

DF: discriminant function**.**

Table (6): Univariable regression analysis for age estimation

Variable	Coefficient	95% CI Lower	95% CI Upper	SE	Test statistic	p-value	R2†
Constant	45.72	35.79	55.65	5.03	9.08	<0.001*	0.015
MLR	-0.35	-0.72	0.01	0.18	-1.93	0.055	
Constant	42.96	33.75	52.17	4.67	9.20	<0.001*	0.007
MLL	-0.24	-0.57	0.08	0.16	-1.49	0.138	
Constant	36.26	21.96	50.56	7.24	5.01	<0.001*	-0.006
APR	0.00	-0.38	0.37	0.19	-0.02	0.985	
Constant	43.80	28.96	58.65	7.52	5.82	<0.001*	0.00
APL	-0.20	-0.59	0.19	0.20	-1.03	0.306	
Constant	44.41	34.40	54.41	5.07	8.76	<0.001*	0.01
SIR	-0.23	-0.51	0.04	0.14	-1.66	0.099	
Constant	39.19	29.09	49.29	5.12	7.66	<0.001*	-0.004
SIL	-0.09	-0.37	0.19	0.14	-0.61	0.545	
Constant	-9.63	-25.99	6.73	8.29	-1.16	0.247	0.143
IMD	1.31	0.84	1.77	0.24	5.55	<0.001*	
Constant	9.06	-14.46	32.58	11.92	0.76	0.448	0.023
BZD	0.28	0.04	0.53	0.12	2.28	0.024*	
Constant	17.72	1.10	34.34	8.42	2.10	0.037*	0.021
ALAR	0.23	0.02	0.43	0.10	2.20	0.029*	
Constant	14.46	-2.21	31.12	8.44	1.71	0.089	0.031
ALAL	0.27	0.06	0.49	0.11	2.58	0.011*	
Constant	39.83	35.16	44.50	2.37	16.82	<0.001*	0.001
Vol. R	-0.20	-0.43	0.03	0.12	-1.68	0.095	
Constant	38.55	33.76	43.33	2.42	15.91	<0.001*	0.001
Vol. L	-0.12	-0.35	0.10	0.12	-1.07	0.287	

† R2 values are based on leave-one-out cross-validation, CI Confidence Interval, SE Standard Error

Table (7): Multivariable regression analysis of each sex to estimate the age.

Gender	Variable	Coefficient	95% CI Lower	95% CI Upper	SE	Test statistic	p-value	R2†
Male	Constant	-65.65	-121.23	-10.08	27.95	-2.35	0.021*	0.232
	APL	-0.33	-0.94	0.29	0.31	-1.05	0.295	
	IMD	1.29	0.56	2.03	0.37	3.51	<0.001*	
	BZD	0.3	-0.22	0.83	0.26	1.15	0.253	
	ALAR	0.18	-0.2	0.56	0.19	0.94	0.348	
	ALAL	0.31	-0.07	0.7	0.19	1.63	0.107	
Female	Constant	-30.93	-78.29	16.43	23.81	-1.3	0.198	0.111
	APL	-0.02	-0.58	0.54	0.28	-0.08	0.939	
	IMD	1.31	0.57	2.06	0.37	3.52	<0.001*	
	BZD	0.09	-0.23	0.41	0.16	0.54	0.590	
	ALAR	0.11	-0.2	0.41	0.15	0.71	0.480	
	ALAL	0.07	-0.26	0.4	0.17	0.41	0.686	
Overall	Constant	-46.4	-79.48	-13.32	16.76	-2.77	0.006*	0.188
	APR	0.45	-0.11	1.01	0.28	1.59	0.113	
	APL	-0.51	-1.08	0.06	0.29	-1.75	0.082	
	IMD	1.28	0.81	1.76	0.24	5.3	<0.001*	
	BZD	0.12	-0.13	0.38	0.13	0.94	0.349	
	ALAR	0.2	-0.04	0.44	0.12	1.67	0.096	
	ALAL	0.15	-0.08	0.39	0.12	1.28	0.203	

† R2 values are based on leave-one-out cross-validation, CI Confidence Interval, SE Standard Error * Significant (p<0.05).

Discussion

Forensic sciences define identity as an individual's recognition of their uniqueness, whether they are living or dead. A person can be identified by age, sex, ethnicity, and appearance (Aishwarya et al. 2021). Identification of decomposed human remains is one of the most difficult skills (Bangi et al. 2017). Because of the relatively non-breakable hard tissues existing in the craniofacial region, there is a high probability that the zygomatic complex and maxillary sinuses will remain intact to be used in the identity process (Chaurasia and Katheriya 2016; Bangi et al. 2017). Hence the present study was framed to determine the reliability of the maxillary sinus dimensions and bizygomatic distance as methods for sex determination and age estimation using CBCT.

While the width and length of the MS reach adult proportions by the age of 12 years, the height increases continuously up to the age of 18 years (Whyte and Boeddinghaus 2019) thus, the age of patients included in this study started from 18 years. When MS reaches the adult size, the pneumatization starts again after the extraction of the teeth (Deshpande et al. 2022) therefore, only patients with fully erupted maxillary teeth with/without third molars were involved in this study.

In this study, the age range was (18-60 years) and patients were divided into three age groups according to their chronological age. According to Diaz et al. (2012) this is the young adult and adult age stage. Throughout adulthood, the head and face change continuously due to growth and remodelling of bone as a part of the normal aging process. However, these changes in the bony tissues do not always lead to predictable changes in the overlying muscles and skin (Albert et al. 2007).

In the current study, mean values of MLR and MLL were significantly higher in males than females (p=0.001) (p=0.002). Also, APR, APL, SIR, SIL and Vol. of the right and left MS were significantly higher in males (p=0.000). These results are consistent with many previous studies that evaluated exactly the same variables (Ekizoglu et al. 2014; Kanthem et al. 2015; Gomes et al. 2019; Lima et al. 2020). Similarly previous studies (Teke et al. 2007; Uthman et al. 2011; Tambawala et al. 2015; Akhlaghi et al. 2017; Bangi et al. 2017; Gamba et al. 2017; Sherif et al. 2017; Fajarwati et al. 2020; Soares et al. 2020; Kannampurath et al. 2023) revealed that ML, AP and SI of males were significantly higher than females.

Furthermore, many studies reported various variables that were significantly higher in males than females. Dangore-Khasbage and Bhowate (2018) reported that only parameters of right MS were significantly high. MLL, SI of both sides and Vol.L MS were recorded by Ibraheem et al. (2020), SI of both sides and Vol.L MS by Amin and Hassan (2012), AP and Vol. of MS of both sides by Sharma et al. (2014), SI of both sides and APL by Deshpande et al. (2022) and AP of both sides by Santiago de Mendonça et al. (2021).

In many studies, (Jehan et al. 2014; Paknahad et al. 2017; Aishwarya et al. 2021; Tiwari et al. 2023) ML of both sides was the only non-significant variable. Also, Sahlstrand-johnson et al. (2011) found that MLL was the only non-significant variable. In contrast, Urooge and Patil (2017) reported that MLL of the sinus is the solitary higher significant parameter in males than females. On the other hand, Ibraheem et al. (2020) reported that AP of both MS was larger in females than males but this finding was statistically insignificant. Whereas, Chaurasia and Katheriya (2016) found that all MS measurements were statistically non-significant. This result is supported by previous studies (Saccucci et al. 2015; Etemadi et al. 2017) concluded that MS could not be used as a reliable indicator for sexual identification.

Regarding ALA, this study revealed a non-significant higher mean value in females than males of both sides. Opposite to this result Dangore-Khasbage and Bhowate (2018) found a significant higher mean values of ALA in males. As a result of this study, IMD revealed non-significant higher mean value in males, this is similar to many studies (Jehan et al. 2014; Hemanthakumar et al. 2022; Tiwari et al. 2023) and contrary to Lima et al. (2020). According to this study, BZD recorded a significantly higher mean value in males (p=0.000). Many previous studies agree with this result (Jehan et al. 2014; Chaurasia and Katheriya 2016; Aishwarya et al. 2021; Hemanthakumar et al. 2022; Meral et al. 2022; Patil et al. 2022).

This is may be explained by bigger body size in males than females, so they need to have larger lungs to support their comparatively massive muscles and body organs, resulting in physiological changes in their MS and nasal cavity to be larger to accommodate respiration related needs such as warming and humidifying inhaled air (Sharma et al. 2014; Dangore-Khasbage and Bhowate 2018).

It was revealed by this study that no significant difference between age groups regarding ML, AP, SI and Vol. of MS of both sides, this is compatible with Tiwari et al. (2023). Also, Sahlstrand-johnson et al. (2011) mentioned that no correlation between the Vol. of MS and age. Chaurasia et al (2016) found that there was no significant difference between ML and AP of both sides and age groups. Also, there are previous studies on samples of Egyptians, El Baz et al. (2019) who found no significance of the perimeter of maxillary sinuses between different age groups and Najem et al. (2020) who reported that there is no statistical significance between the diameters of maxillary sinus between young and older groups. Both of them had the same age range like this study but our sample size was larger. On the other hand, Lima et al. (2020) revealed that APL and SI and Vol. of both sides of MS were significantly larger at the young age group.

In the current study, ALAR showed no significant difference between age groups. ALAL and IMD showed no significant difference between Group II and Group III, however a significantly lower value recorded in Group I ($p=0.018$) ($p=0.000$) respectively. Similarly, Lima et al. (2020) found that IMD was of significantly lower values in young group than the old one, while Hemanthakumar et al. (2022) and Chaurasia et al (2016) reported no significant difference between IMD and age. This study reported that the mean value of BZD displayed no significant difference between age groups, this is consistent with Chaurasia et al (2016) and Aishwarya et al. (2021). Conversely, Hemanthakumar et al. (2022) and; Patil et al. (2022), found a significant difference in BZD among the age groups. This study revealed a weak positive correlation between IMD and both BZD and the volume of MS. Also, BZD showed a weak positive correlation with the volume of MS. The volume of maxillary sinus on both sides showed a very strong positive correlation.

Although the means of most measured variables revealed decreasing in values with age, there was no statistical significance. This may be due to the age range selected in the study as patients > 60 years excluded to be easy to find patients with upper posterior maxillary teeth.

Discriminant function analysis was performed for sex prediction. SIR was the most pronounced variable in the differentiation of sex with overall of accuracy 69.44%. Adding all variables to the model result in improvement of the overall accuracy to be 73.89%. Similarly, a study by Lima et al. (2020) revealed that SIR was the best discriminator with overall accuracy 66.9% and when all parameters combined, the overall accuracy increased to 73.6%. Furthermore, Uthman et al. (2011) and Kannampurath et al. (2023) found that SI was the most effective variable for sex prediction with accuracy of 71.6% and 69.5% respectively. Whereas adding other variables to the model resulted in increasing the accuracy to 73.9% in Uthman's study, it did not cause any improvement of the overall accuracy in Kannampurath's study. Paknahad et al. (2017) reported similar result regarding SI but of higher accuracy 76%. Tambawala et al. (2015) recorded the highest accuracy using SI; 90% for right side and 83.3% for left side.

Amin and Hassan (2012) revealed that the SIL and Vol.L had the highest overall accuracy 58.31% and 60.4% respectively and when the two variables combined together the accuracy increased to 66.7%. Sharma et al. (2014) found that the best discriminant variable was AP with overall accuracy 69.81%, while when multivariant analysis performed the accuracy decreases to 67.03%. A study by Dangore-Khasbage and Bhowate (2018) recorded that ALAL is the best variable in sex discrimination with accuracy of 78.5% and when MS measurements were used, the overall accuracy increased to 86%. Ibraheem et al. (2020) reported that the best variable in identifying sex was MLL with accuracy 64% and the overall accuracy was 80% in males and 88% in females. Kanthem et al. (2015) measured the percentage of sexual dimorphism where Vol.R and Vol.L showed the highest percentages of 85.46% and 78.38% respectively.

Many previous studies revealed various multivariable results; Teke et al. (2007) reported that the ability Vol. of MS to identify sex was 69.3%. Ekizoglu et al. (2014) and Sherif et al. (2017) revealed that the overall accuracy of MS measurements was 77.15% and 74% respectively. Santiago de Mendonça et al. (2021) recorded that the overall accuracy of all MS measurements of 67.5%. The highest accuracies were reported by Bangi et al. (2017) and Meral et al. (2022) at 88%, followed by Gomes et al. (2019) at 84%.

Multivariable discriminant function analysis was performed for each age group to predict sex. The oldest age group (42-60 years) presented the best discriminative ability with a sex prediction accuracy of 77.61%. Younger age groups (30-41 and 18-29 years), revealed accuracies of 74.07% and 69.49% respectively. Contrary to these results, Akhlaghi et al. (2017) reported that the highest accuracy for sex determination was detected in the younger age group at 74.3% using maximum distance of both maxillary sinuses but by increasing age, the accuracy decreased to be 65.7% in the older age group. This discrepancy may be due to the difference in the included variables in the models of each study and the criteria of the selected sample, as patients included in our study were with fully erupted maxillary molars. According to Sharan et al. (2008), secondary pneumatization of MS occurred more easily after tooth extraction which may affect results.

For age estimation, linear regression analysis was performed. IMD had the highest overall prediction and followed by ALAL R2 = 0.143 and 0.031 respectively. When all variables were combined together, the value increased to R2 = 0.188 but still of low value. Thus, according to this study, for now, the age could not be estimated precisely using these parameters. Multivariable regression analysis revealed that the age could be estimated, to some extent, in males more than females R2 = 0.232 and 0.111 respectively. In agreement with this study, Lima et al. (2020) recorded that the IMD is the best variable for age estimation at 63.1% followed by Vol.L of MS at 56.2%, when all parameters were combined, the overall accuracy was 67.6%. While, Chaurasia et al (2016) found IMD, AP and ML of MS significantly predicted age. Up to our knowledge, there is a significant lack of studies concerning age prediction, so further studies are needed to cover this point.

Divergent results of the cited studies may be due to differences in methods and statistical analysis, radiographic techniques, numbers of samples, ethnic and racial differences, genetic and environmental factors, anatomical variations in the sinuses and differences in pneumatization process in different age and sex groups (Jehan et al. 2014; Gomes et al. 2019; Fajarwati et al. 2020; Lima et al. 2020).

Conclusions

According to this study, the use of maxillary sinus dimensions and BZD may be valuable for sex determination. All mean values of MS measurements and BZD were significantly higher in males except ALA and IMD. The most discriminant variable for sex determination was SIR. Also, the older age group 42-60 years had the best discriminative ability with a sex prediction. Conversely, these variables revealed poor results in age estimation. Only, IMD had the highest ability for age prediction. Age could be estimated, somewhat, correctly in males more than females but of low performance.

Limitations

Further studies are needed to conduct these analyses on a larger sample size as Egypt is a country with large and wide population variety. Also, the study was retrospective, it was not possible to study the correlation between the measurements of maxillary sinuses and BZD and patient's size or body stature.

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Author 3: Writing, editing and reviewing the manuscript.

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