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Linear and Volumetric Assessment of Maxillary Sinus Using Cone-Beam Computed Tomography (CBCT)

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Abstract:

Background: This research was designed to assess the maxillary sinus dimensions linearly & volumetrically considering age, gender, and side in a sample of the Egyptian population utilizing cone-beam computed tomography (CBCT).

Patients & Methods: This research has been performed on 100 cone-beam computed tomography scans belonging to 34 males & 66 women, CBCT scans were classified according to gender, age and side (right and left). The Mimics Research TM software has been utilized for evaluating all maxillary sinuses' dimensions, enabling manual and semi-automatic calculations of MSV.

Results: All sinus measurements were statistically significantly lower in females than males. There was no statistically substantial association amongst age & all sinus measurements. Sinus volume measurements using formula showed significantly lower values than those using software.

Conclusion: Linear & volumetric measurements of maxillary sinus in the Egyptian people are comparable to those of other populations considering the difference in ethnicity and environment. There were no associations between maxillary sinus linear or volumetric measurements and patients' sides.

Keywords: Maxillary sinus, volumetric analysis, CBCT.

1. Introduction

The maxillary sinus (MS) is an air-filled hollow chamber with mucoperiosteum membrane lining it, and ciliated cylindrical pseudostratified epithelium covers it. The nasal cavity's lateral wall forms its base, which is oriented medially, and its apex extends into the zygomatic bone[1]. Owing to vital position of the maxillary sinuses to the area where dentists work. The maxillary sinus anatomy is critical for the prevention of potential complications in maxillofacial surgery, as well as for the preoperative assessment of dental implant therapy & the graft size calculation needed for a sinus lift. In forensic dentistry medicine, the MS may be utilized for detecting sex in cases where the entire body can't be located [2].

The Maxillary sinus volume were evaluated utilizing several procedures, involving medical computed tomography scan, magnetic resonance imaging, & currently Cone beam computed tomography, cone-beam computed tomography offers lesser radiation dose, multiplanar sinus reconstruction, & isotropic volume resolution[3].

Segmentation is used for diagnosis, surgical planning simulation, radiation treatment, guiding minimally invasive surgeries, volume assessment, and 3D post-processing procedures[4].

In clinical dental practice, 3D segmentation is used to extract a group of voxels from data based on their intensity and density accurately. This process is important for classifying different anatomical structures, due to the MS's proximity to other significant anatomical features such as the infraorbital nerve, canine fossa, and nasal passages, segmentation of the MS is difficult and time-consuming. Additionally, the segmentation is made more challenging by the issues of mucosal thickening, inflammation, cavity atrophy, and individual variances[5].

There are three methods for segmentation manual, semiautomatic, and automatic Methods for manually segmenting the maxillary sinus in magnetic resonance imaging (MRI) & computed tomography (CT) are adequate but need to draw contours slice by slice & erase areas of the MS, that is time-consuming & depend on the doctor´s experience, semi-automatic procedures are primarily utilized for segmentation in a variety of open-source software, resulting in an increase in segmentation effectiveness. Nevertheless, manual erasing & adjustment are still necessary due to the maxillary sinus 's connection to other cavities [6, 7].

Among the deep learning methods that has demonstrated exceptional presentation in analyzing images is the automatic segmentation that is based on artificial intelligence, the convolutional neural network (CNN). It utilizes multi-layer neural computational contacts to perform image processing tasks, including segmentation & classification [8].

Patients & Methods

Study setting and population:

This cross-sectional retrospective descriptive research performed on randomly selected 100 CBCT scans (sixty-six female and 34 males varied in age among 18 - 62 years with average age of 29.5 ± 10.7 years). The CBCT scans were retrieved from the archives of the CBCT units, faculties of dental medicine, Al-Azhar University (Assiut Branch) and Assiut University & several private radiology centers between 2022-2023 as a part of radiographic diagnostic procedures for several causes like dental implants, prosthetics, periodontics, orthodontics. and endodontics.

Inclusion criteria included images for patients ≥18 years of age, CBCT images with great geometric resolution and availability of precise information about patients' age and gender. The excluding criteria included images with low quality, images with pathological conditions otherwise a trauma that impacted the integrity or anatomy of the MS, presence of metal restoration in the upper posterior area, and lack of any posterior teeth within the maxilla and mandible except third molar.

Radiographic assessment of MS:

CBCT images were processed & observed with Mimics Research TM software version 21.0. 3 experienced radiologist observers evaluated all images. The analysis was performed in a quiet environment with adequate lighting. The anatomic variations in the MS measurements have been evaluated & divided regarding gender (male & female), age (less than or equal 40 years and more than 40 years), and side (right & left).

Linear measurements of MS:

In the axial & sagittal reconstructions, the horizontal reference line has been situated from the anterior to the posterior of the nasal spine, parallel to the ground, while the software vertical reference line was situated in the median sagittal plane perpendicular to the ground. This orientation was used for each cone-beam computed tomography exam. Subsequently, the examiners were capable of conducting a dynamic assessment of the entire image volume &identifying the maximum measurements of the MS's length, width, and height [9]. The following techniques were utilized to conduct the MS's morphometric analysis. The longest distance perpendicular from the medial wall of the sinus to the most lateral wall of the lateral process of MS is the width (axial view). Length (axial view): The Medial Wall's greatest distance from the most anterior to the most posterior point. Height (coronal view): The longest distance between the lowest point of the sinus floor and the greatest point of the sinus roof [10].

Sinus volume determination:

1-Volume determination via segmentation technique using Mimics Research TM software version 21.0 (NV, Technologielaan 15, 3001 Leuven, Belgium) with the following sequences: - First, we used the dynamic region grow, smart expand, edit mask until obtaining accurate borders of MS, finally right click on mask to choose calculate part icon. **figure -1**

2- Volume estimation through geometric calculation in accordance with the geometrical equation: Pyramid Volume:- 1/3 pyramid height × pyramid base Length × pyramid base width[11]. **fig -1**

Statistical analysis :

The distribution of quantitative data was examined for normality utilizing the Kolmogorov-Smirnov &Shapiro-Wilk tests. (Sinus height, length, & width data demonstrated a normal (parametric) distribution although sinus volume data demonstrated abnormal (non-parametric) distribution. Quantitative data were detected as mean, standard deviation, 95% Confidence Interval (95% CI), and range values. For parametric data, Student's t- test has been utilized for comparisons among males and females in addition, for comparing among the two age groups. Paired t-test has been used in comparing among left & right sides. For non-parametric data, Mann-Whitney U test has been utilized for comparisons among males & females as well as for comparing among both age groups. Wilcoxon signed-rank test has been utilized for comparing among left & right sides in addition to compare among sinus volume measurements by formula and software. Frequencies and percentages were utilized for expressing qualitative data. The significance level was established at $P \leq 0.05$. IBM SPSS Statistics for Windows, Version 23.0, was utilized to conduct the statistical analysis. IBM Corp., Armonk, NY.

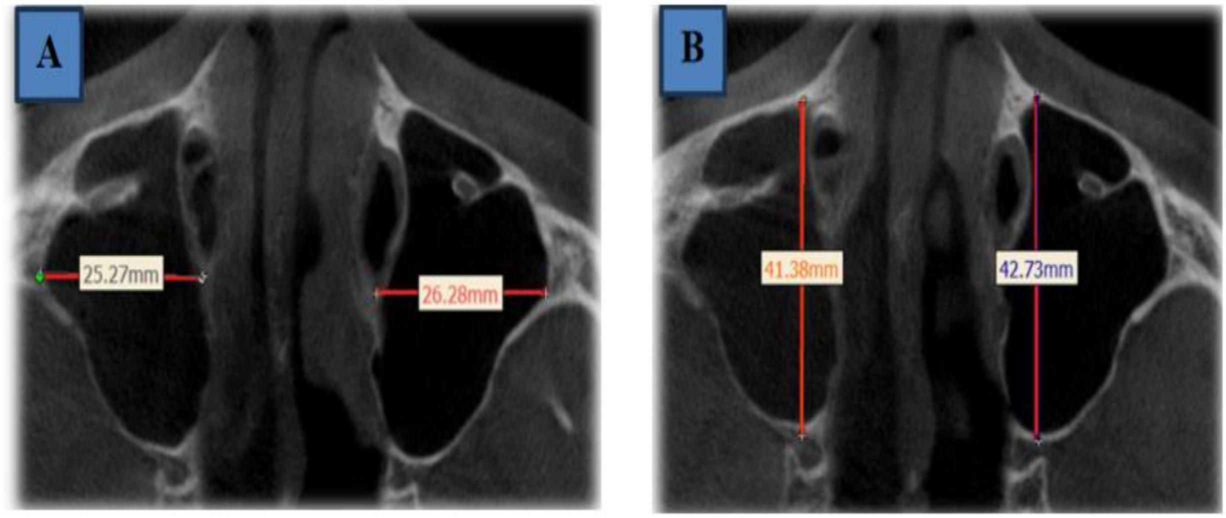

Figure (1): *Linear measurements of maxillary sinus width (A), length(B), and height(C)*

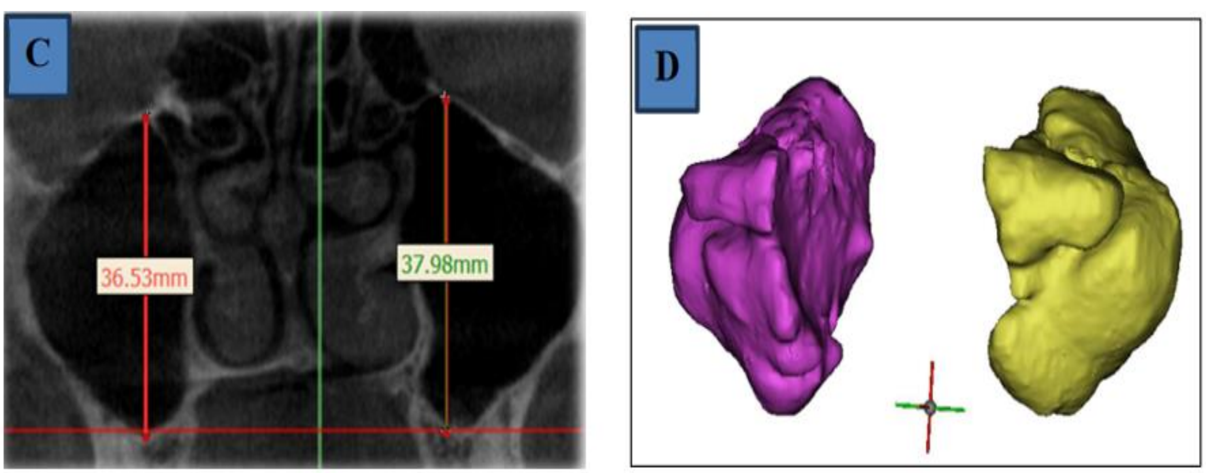

Figure (1): *CBCT images of coronal and axial cuts of a female patient aged 62 years showing(a)width (b)length (c) height (d) Three-dimensional model of both right & left MS*

Results

The selected Cone-Beam Computed Tomography images have been assessed, & the maxillary sinuses have been determined and categorized regarding age, gender, & side. **(Tables 1-3)**.

Table1: Descriptive statistics & outcomes of Student's t-test for the association among gender & sinus height, length, and width measurements (mm) & Mann-Whitney U test for the association among gender and sinus volume measurements (mm3).

Measurements (mm)	Female (n = 132 sinuses)		Male (n = 68 sinuses)		P-value
	Mean	**SD**	**Mean**	**SD**	
Sinus height	33.69	5	38.61	5.58	<0.001*
Sinus length	37.66	3.89	39.87	3.87	
Sinus width	26.48	5.61	29.76	5.37	
	Median (Range)	**Mean ± (SD)**	**Median (Range)**	**Mean ± (SD)**	
Formula	11988.2 (2177.5 – 21454)	11697 ± (4335.1)	14805.2 (5301.8 – 35227.6)	15817.6 ± (5696.5)	
Software	13024.3 (2318.2 – 200177.9)	14238.1 ± (16927.4)	16154.5 (6788.2 – 38298.7)	17209.8 ± (5930)	

**: Significant at (P-value <0.001)*

Females showed statistically significantly lower mean sinus height, length, width, and volume measurements than males (P-value <0.001)

Table 2: Descriptive statistics & outcomes of Student's t-test for the association among age group and sinus height, length, and width measurements (mm), and Mann-Whitney U test for the association among age group & sinus volume measurements (mm3)

Measurements (mm)	18-40 years old (n = 174 sinuses)		41-62 years old (n = 26 sinuses)		P-value
	Mean	**SD**	**Mean**	**SD**	
Sinus height	35.48	5.73	34.59	5.45	0.157
Sinus length	38.38	4.1	38.6	3.39	0.054
Sinus width	27.73	5.9	26.69	4.45	0.181
	Median (Range)	**Mean ± (SD)**	**Median (Range)**	**Mean ± (SD)**	**P-value**
Formula	12993.1 (2177.5 – 35227.6)	13213.1 ± (5342.9)	12645 (4098.7 – 20172)	12327.8 ± (4203.8)	0.509
Software	13801.6 (2318.2 – 200177.9)	15532.4 ± (15142.6)	13515.1 (4787 – 21719.9)	13348.7 ± (4526.6)	0.414

**: Significant at (P-value = 0.457, Effect size = 0.157).*

Statistically insignificant variance was observed among mean sinus length, height, volume, & width measurements within both age groups (P-value = 0.457, Effect size = 0.157).

Table (3): Descriptive statistics & outcomes of paired t-test for the association among side and sinus height, length, and width measurements (mm), and Wilcoxon signed-rank test for the association among side & sinus volume measurements (mm3).

Measurements (mm)	Left side. (n = 100 sinuses)		Right side (n = 100 sinuses)		P-value
	Mean	**SD**	**Mean**	**SD**	
Sinus height	35.53	5.86	35.2	5.54	0.203
Sinus length	38.51	4.19	38.31	3.84	0.336
Sinus width	27.95	5.65	27.24	5.82	0.012*
	Median (Range)	**Mean ± (SD)**	**Median (Range)**	**Mean ± (SD)**	**P-value**
Formula	13284.7 (2179.6 – 35227.6)	13368 ± (5334.3)	12575.4 (2177.5 – 30611.7)	12828± (5091.6)	0.006*
Software	13801.6 (2318.2 – 200177.9)	16187.1± (19402.6)	13709.3 (2384.6 – 34817.8)	14309.9± (5358.7)	0.424

**: Significant at (P-value = 0.203).*

Statistically insignificant variance was observed among mean sinus height & length measurements within both sides (P-value = 0.203), the left side demonstrated statistically significantly greater mean sinus width measurements compared to right side (P-value = 0.012). As regards volume measurement by formula, left side demonstrated statistically significantly greater sinus volume comparing with right side (*P*-value=0.006). Statistically insignificant variance was observed among sinus volume measurements by software in the two sides (*P*-value = 0.424).

Discussion

The MS is the initial & greatest paranasal sinus to form. It is a pneumatic space that is bilaterally situated within the body of the maxilla & opens into the middle nasal meatus of the nasal cavity via single or several openings (maxillary ostium). Various shapes of the maxillary sinus have been reported, including triangular, leaf, scapular, and renal. Triangular sinuses are the most frequent shape in males & females [(12)].

The evaluation of MSV in academic literature utilized lateral cephalograms, pantomograms, CT scans, MRIs, & dry and cadaveric skulls but, anatomical calculations from cadavers are inaccurate because of soft tissue loss so the most reliable method is the segmentation to evaluate sinus volume[(13)].

Maxillary sinus volume (MSV) significantly affects different dental procedures such as endodontics, periodontal flap surgery, apicectomy, dental implants, tooth extraction, orthognathic surgeries, & operating intervention for maxillary sinus occupying lesions. This is especially true once the sinus is large, & the premolars & molars roots are close to it [14].

Because conventional dental and panoramic radiographs provide an approximation of sinus dimensions, they were unsuitable for volumetric analysis of the MS owing to their two dimensional nature[15].CBCT is an advanced digital imaging technique that offers three-dimensional information about the teeth & the maxillofacial area, assists in diagnosis & advances clinical decision-making in treatment planning. Because of the MS anatomical complexity, CBCT has become an essential radiographic method for its evaluation[16, 17].

It has also been claimed that there is no appreciable difference between linear CBCT measurements and direct measurements of the jaw and facial structures. To avoid problems and take precise measurements in the appropriate area, it is necessary to evaluate anatomical structures using CBCT[18]. This research aimed to evaluate the MS dimensions linearly & volumetrically considering age, gender, and side in a sample of the Egyptian people utilizing CBCT. Three skilled radiologists, one of whom was a professor, reviewed each image. They were well trained, calibrated, and experienced in distinguishing features and landmarks associated with the area of interest. In a peaceful setting with sufficient lighting.

The maxillary sinuses weren't impacted by any pathology (fracture, inflammation, residual root, or condition needing operation or trauma) or by any feature which influenced their anatomy, size, shape, or integrity in the images chosen in this research [2]. cases' images without lost teeth in the mandibular & maxillary posterior areas excluding the third molars because of natural tendency of the MS to pneumatize bone throughout life & the inherent bone remodeling, that follow loss of teeth and affecting MS linear and volumetric measurements.

Patients were aged ≥18 years as it is the time for complete ossification of the skull base. The maxillary sinus achieves its maximum size within the age of eighteen with the end of midface growth & the eruption of the maxillary teeth [19], 2 age groups (18-40) & 41–62) years were used to categorize the age groups in the recent research. The goal was to illustrate the impact of ageing on bone remodeling and dimensional changes in anatomical structures by including both younger and older age groups[20].

In comparison of this study with studies which were done on Korean and Iraqi population samples there were no obvious differences regarding width and length both male and female groups, on the other hand the maximum mean height dimension in this study(38.6) was less in both male and female than Korean 47.88mm) and Iraqi (45mm)[21, 22], and more than that of Swedish population(34mm)[23].

In a study conducted on Turkish population reported that the mean right & left MSVs were 14490±3.998, and 14590±3.984 mm3 respectively, as well in this research the mean right & left MSVs were 13709.3, and 13801.6.1mm3m respectively with no clear differences in MSV between these studies[2].

Regarding gender upon examination of MS linear measurements this study showed that females had statistically significantly lower values than males, these findings were in accordance with other studies made on Brazilian, Indian, Iranian,Iraqi, and Korean populations using CT and CBCT[20, 24, 25], on the other hand, another study detect insignificant variances among men & women in the linear measurements of maxillary sinus[12], while a study made on adult Iranian patients reported that Men & women exhibited statistically significant variations in both height &length. Nevertheless, there was statistically insignificant variance among men & women in terms of the width of the MS on the two sides [26].

The findings of the current investigation also showed that females showed statistically significantly lower sinus volume measurement than males that corroborates other studies[2, 23]. This conclusion, however, was in contrast to other study findings, which discovered that no variance was observed among men & women MSVs[27]. Additionally, the MS role in ethnic classification was determined to be that European crania had significantly greater antral volumes compared to Zulu crania, & men had a greater volume compared to women. On the other side, the sinuses of Zulu men were narrower compared to those of Zulu women, which is inconsistent with the findings of the current research. Additionally, race has been determined to be greatly significant, as European sinuses were broader compared to those of Zulu [28].

In the current investigation, a comparison between age groups (18-40 and (62-41years MS dimensions (width, length, Volume, & Height) within male & female discovered that statistically insignificant variance was observed. This coincides with a study conducted to evaluate age-associated variations in bone architecture, the study found that in people over the age of sixty-five variations begin to happen in the cortical bone, there is a decrease in the number of Volkmann's & Haversian channels & most osteoblasts become hollow. In the cancellous bone, the trabeculae become thin, which leads to more space in the medullary cavity. This space is often filled with adipocytes and fat cells, other studies confirmed these results, particularly in explaining age-associated variations in trabecular bone in humans more than fifty years old[29, 30], There are no associations among age & MSV, with the exception of pathological phenomena. It is widely recognized that the sizes of the paranasal sinuses remain constant until mortality [31]. However, another study found that (18-40) years old group demonstrated statistically greater values compared to that of the group >(41-62) years[20, 32].

In the present study sinus volume measurement by formula showed statistically significantly lower value than by software (P-value <0.001, while in another study, in order to evaluate the automatically segmented sinus from multi-slice computed tomography scans collected with a 128-slice computed tomography scanner, Somatom Definition AS+ (Siemens Healthcare), & Syngo Via for Oncology Siemens software, the &MSV was estimated utilizing mathematical formulae of sphere, pyramid, as well as the mean of sphere & pyramid. The automatically segmented volume of the MS was determined to have a 0.99 correlation coefficient, & there was statistically insignificant variance among it and the mathematically estimated volume utilizing the sphere &pyramid formulas. The sphere formula produced a larger volume, the pyramid formula produced a smaller volume, and the mean of the two was closest to the automatically segmented volume. For this reason, it was determined that the MS shape is intermediate among a pyramid &a sphere [32].

Conclusion

1- linear & volumetric measurements of MS in the Egyptian people are comparable to those of other populations considering the difference in ethnicity and environment.

2- Linear & volumetric measurements of MS in the Egyptian people showed statistical significance higher values in males than females with no associations between age and maxillary sinus linear or volumetric measurements between Egyptian adults.

Ethical issues; The research protocol was permitted under the number of (AUAREC202200001-07) by the ethical committee, Faculty of Dental Medicine, Al- Azhar University (Assiut branch).

Conflict of interests: Non declared

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Authors' contributions: Every single author made a contribution to the conceptualization & design of the investigation. The preparation of the materials, the collection of data, the analysis, & the writing of the article were all performed by all of the writers.

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