ORIGINAL RESEARCH

Volumetric Analysis of Maxillary Sinus Employing CBCT, Enhanced with MIMICS and ITK-SNAP – A Comparative Study.

Swetha Paspuleti[1], Yasaswi Ponukupati[3], KSV Ramesh[2], Ravikanth Manyam[1], A. Naga Supriya[1], Smita Shrishail Birajdar[1]

Abstract

Introduction: The maxillary sinus is of great interest with its intricate relationship to the Oro maxillofacial structures, serving as a narrative investigative tool for age and gender estimation in forensic dentistry. Numerous software programs are utilized in medical surgeries to analyse and print reconstructive organs. Among these, ITK-SNAP and MIMICS are particularly useful for volumetric estimation of sinuses using cone beam computed tomography scans.

Aim: The aim of this study is to evaluate maxillary sinus volumes using CBCT scans and compare the analysis provided by two different software programs, ITK-SNAP and MIMICS, in terms of age-gender estimation.

Materials and Methods: This study was performed in 154 patients selected by a retrospective review of the archives of the Vishnu dental college, Department of Oral Radiology. Patients were divided into five age groups (18–24 years, 25–34 years, 35–44 years, 45 years) and by sex. Cone-beam computed tomography (CBCT) images of the patients were transferred to the MIMICS & ITK-SNAP software and the Maxillary Sinus Volume (MSV) was measured. All statistical analyses were performed using the SPSS (Statistical Package for Social Sciences, version 21) software.

Results: There was no statistically significant difference between the right and left maxillary sinus volume according to the findings obtained from our study, and maxillary sinus volume in males was found to be significantly higher than that of females. Another finding of our study is that the maxillary sinus volume decreases with age increase. Especially it was also found that the sinus volume in males in the 18–24 age group was statistically significantly. A strong positive Pearson correlation coefficient of .798 was obtained between “MIMICS” and “ITK-SNAP” for maxillary sinus volume, which is highly statistically significant (p-value = .000). This indicates a robust positive linear relationship between the maxillary sinus volumes obtained through “MIMICS” and “ITK-SNAP” methods.

Conclusion: Consequently, maxillary sinus volume measurements can be made on CBCT scans using reconstruction software. For measuring and segmenting, the ITK-SNAP program is suggested since it provides a dependable and easy-to-use semiautomatic approach that made the study’s findings possible.

Keywords: Cone Beam Computed Tomography, ITK-SNAP, Maxillary Sinus, MIMICS Volumetric Analysis

Introduction

Forensic dentistry is known for its novel investigatory methods employed to recognize unidentified and unclaimed bodies, most of which make age – gender estimation tedious.[1-3] Such situations are challenging in major catastrophes where greater accuracy is required. Usually, the pelvis and skull are the gold standard specimens used to make a precise diagnosis.[4] However, if unavailable, the maxillary sinus can be used as a subsidiary specimen for diagnosis. The literature states that even in high crush injuries or blows expected, maxillary sinus anatomy is not easily disfigured, which allows its inclusion in forensic investigations. Many situations arise if the whole structure is burned, dissolved, or isolated, which makes the procedure even more arduous.[5,6] Because of its unique architecture and closeness to other oral structures, the maxillary sinus is of significant interest to dentists. Understanding it can assist avert difficulties during maxillofacial surgery. When the full body cannot be obtained, the

Department and Institution Affiliation: [1]Department of Oral and Maxillofacial Pathology and Oral Microbiology, Vishnu Dental College, Bhimavaram 534202; [2]Department of Periodontics and Implantology. Vishnu Dental College, Bhimavaram 534202; [3]Final Year BDS, Vishnu Dental College, Bhimavaram 534202.

Corresponding Author: Swetha Paspuleti, Department of Oral and Maxillofacial Pathology and Oral Microbiology, Vishnu Dental College, Bhimavaram 534202. Email: swetha.p@vdc.edu.in

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maxillary sinus can be utilized as a sex determination method in forensic medicine.

There are different software and methodologies published regarding volumetric analysis of the maxillary sinus (maxillary sinus volumes (MSV)), varying from injecting dies to using an ellipsoid formula. There is a surge of volume measurement programs, both automated and semi-automated, that employ CBCT and MRI images. In medicine, such software is helpful in reconstructive surgeries and help in 3D printing of reconstructed organs. It utilizes bone density and understands using Hounsfield units, thus depicting the structures easily. Even the smallest and structurally complex structure can be picked and separated for better understanding and to enhance detailing. For the purpose of assessing paranasal sinuses, cone beam computed tomography (CBCT) scans are now the recommended imaging technique. CBCT scans, as opposed to standard X-rays, have the ability to distinguish between a variety of structures and airspaces, including bone, teeth, the airway, and paranasal sinuses, while avoiding the drawbacks of 2D pictures.[6,7] This study aimed to assess maxillary sinus volumes using CBCT scans and compare the analysis of two different software's ITK-SNAP and MIMICS for age – gender estimation.

Materials and Methods

A comparative study was conducted by taking CBCT / DICOM (Digital Imaging and Communications in Medicine) images referred for various reasons to Vishnu dental college, oral radiology department retrospectively. The institutional ethics committee accepted the study protocol and assigned it the number IECVDC/23/UG01/OP/IVT/53.

Dentulous CBCT scans, patients subjected to CBCT scans for maxilla required diagnostic and treatment procedures without the history of orthodontics and orthognathic surgery are included in the study.

CBCT scans with pathology in maxillofacial region, artefacts and poor diagnostic quality, completely edentulous scans, scans with craniofacial fractures and developmental anomalies such as palatal cleft, Oral and maxillofacial deformities and patients with history of orthodontic treatment and trauma are excluded from study.

Calculations to determine the sample size were performed for age estimation of maxillary sinus volume as the primary outcome using G*power version 3.1.9.4. The calculations were based on an effect size of 0.08, an alpha level of 0.05, and a desired power of 80%. The estimated sample size was 126 CBCT images.

All CBCT scans were acquired using a CRANEX 3D system (manufactured by SORDEX), which operated with parameters of 90 kVp, 5 mA, and 4.9 seconds of exposure time, resulting in an image area with a voxel size of 300 mm2 and a field of view (FOV) of 6x8cm. The images were recorded in the digital imaging and communications in medicine (DICOM) format, with each DICOM file containing a single frame of 512x512 matrix resolution.

ITK-SNAP : ITK-SNAP (version 3.8, ITK-SNAP, UPenn & UNC, USA)

MIMICS : MIMICS 21.0 software (Materialise HQ Technologielaan, Leuven, Belgium)

CBCT images were collected from the department of oral medicine and radiology then, uploaded for volumetric analysis into the two so called software's ITK-SNAP and MIMICS respectively in a computer . The threshold limit was set between a minimum limit of -1024HU to a maximum of -526HU respectively.

Two lines are used to pick the panoramic cut: a vertical line (V) and a horizontal line (H) at the centre of the arch. These are the specifics:

• The horizontal line is indicated at the maximum mesiodistal extension of the sinus cavity; the vertical line is measured from the lowest point of the sinus floor to its highest position, which is at the orbital floor's boundary. It specifically stretches from the nasal cavity's medial limit wall to the distal wall next to the maxilla's tuberosity. Retrospective collection of CBCT scans from department of oral radiology.

Statistical analyses were performed using SPSS 17.0 software (SPSS Inc., Chicago, IL, USA), and the data are expressed as means ± standard deviations. Independent t test and One-way ANOVA were used for statistical analysis. The mean MSV was compared among groups using Student's t test and one-way analysis of variance. P values >0.01 were considered to indicate statistical significance.

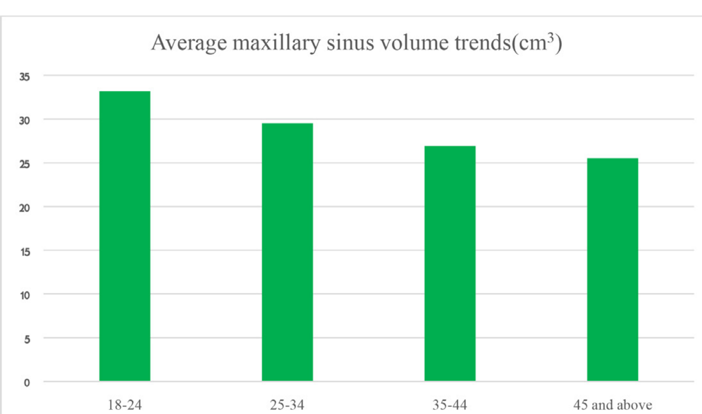

Fig. 1: Maxillary sinus volumes trend as age increases

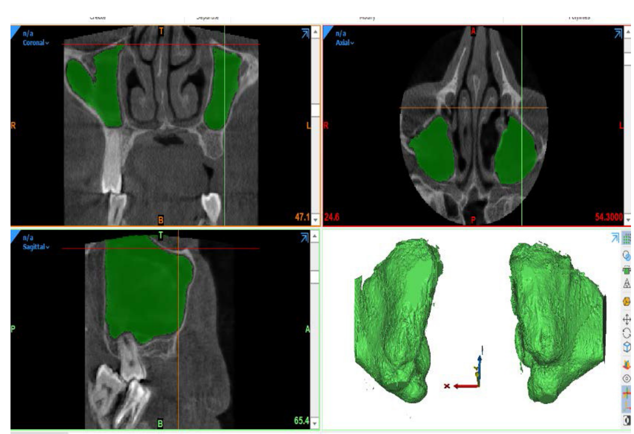

Fig. 2: Three dimensional reconstruction & volumetric analysis of maxillary sinus by MIMICS software

Results

Careful evaluations for MSV, scans were done to prevent any significant difference which were aligned with the statistics with an overall efficiency 97% respectively. All the measurement were found to be highly satisfactory and reproducible in nature ($p>0.01$). The mean values of MSV for women were 32.0 ± 5.33 cm 3 whereas males had a value of 26.5±7.4 cm 3. (Table 1)

In the "MIMICS" group, the mean maxillary sinus volume is approximately 24,247.81, with a standard deviation of 6,846.90. On the other hand, in the "ITK-SNAP" group, the mean maxillary sinus volume is approximately 23,113.33, with a standard deviation of 6,690.50. The calculated p-value for this comparison is 0.19 suggesting that there may not be a statistically significant difference in maxillary sinus volume between the two groups. (Table 2)

A strong positive Pearson correlation coefficient of .798 was obtained between "MIMICS" and "ITK-SNAP" for maxillary sinus volume, which is highly statistically significant (p-value = .000). This indicates a robust positive linear relationship between the maxillary sinus volumes obtained through "MIMICS" and "ITK-SNAP" methods.

Discussion

The intricate anatomy of the maxillary sinus relative to the alveolar bone is a subject of interest, particularly given its complex, variable extensions that defy numerous factors, such as age and sex.[9] The proximity of the sinus to dentofacial structures is crucial for dentists to diagnose and plan treatments.[10] While there are various studies that use CBCT scans to analyse maxillary sinus volumes using different software, this particular study stands out for its comparative examination of manual and automated software versions.[10,11] The scans were retrospectively collected and filtered based on specific criteria.

The maxillary sinus, also known as the antrum of Highmore, is a three-dimensional pyramidal structure with its apex facing the zygoma, making it amenable to volumetric analysis for manual segmentation.[8] The study found a mean MSV value of 29.7±5.14 cm3 for both males and females, with values of 38.5±15.4 cm3 and 30.0±9.33 cm3 for the manual and automated software, respectively. The symmetry between the left and right antrum was evident in this study.

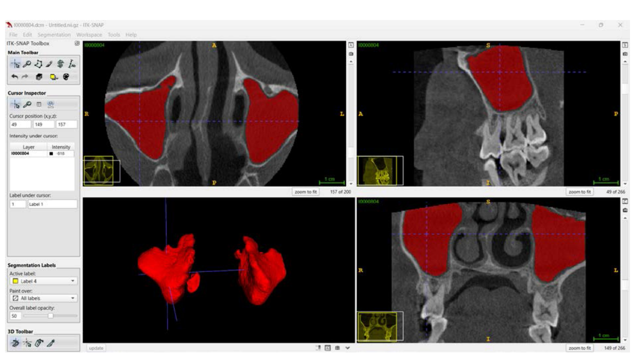

Fig. 3: Volumetric reconstruction models calculated by ITK-SNAP software

Additionally, studies conducted in the past have demonstrated alterations brought about by orthodontic treatment, septum deviation, and sinus diseases, as well as volumetric changes in the maxillary sinus and its link to tooth position. Research has also examined variations in the size and structure of the maxillary sinus according to age, gender, and race; however, the forensic component of these studies has yielded little data.[12, 13] Numerous studies have found a broad range of maxillary sinus diameters, which might be attributed to factors including ethnic and human diversity as well as the induction of pneumatization.[14,15] A number of variables, including the dentition, chewing power, breathing patterns, and craniofacial development factors, might affect the pneumatization of the maxillary alveolar processes.[11,13]

There were differences between the MSV findings of Wu et al.[14] and Kanthem RK et al.[15] The results of the research are consistent with Wu et al's conclusion that there was no significant difference between the left and right MSV and that the MSV was higher in females than in males. However, Kanthem RK et al. found that the right MSV was higher than the left MSV and that the MSV was considerably higher in men than in females. This disparity could result from the maxillary sinus continuing to develop until the second and third decades of life in boys and females, respectively, and then experiencing an age-related decrease in volume.

Researchers[18] have anatomical study indicated that Maxillary Sinus Volume (MSV) increased until age 20 and then decreased; no significant differences were found between right and left MSVs or between the sexes. Our study, which employed a different volume measurement method, found no significant differences between the sexes, but we did find a significant difference between the ages. the beginning stages (18–24 years old) , males had higher MSV than females; how-

Table 1 : Descriptive statistics of average sinus volumes according to side of the sinus, gender and age

GENDER	VARIABLES	N	Average MSV	Std. deviation	P value
Female	Right	102	15.92	4.456	0.3
	left	102	15.02	4.48	0.2
	18-24	33	33.8	5.85	0.01*
	25-34	40	29.2	6.21	0.2
	35-44	20	24.6	3.25	0.15
	44 and above	5	25.3	7.52	0.2
Male	Right	52	13.24	3.285	0.3
	Left	52	14.25	3.875	0.2
	18-24	19	42.05	5.36	0.01*
	25-34	15	38.56	4.21	0.15
	35-44	8	29.34	3.24	0.5
	44 and above	10	26.89	4.14	0.2

*significant

ever, after that point, there were no discernible variations between the sexes within the age categories.(Figure 1) It seems that males may finish the growth and development of their maxillary sinus later in life than females suggesting that continued growth and development of facial norms contributed to an increase in MSV.[19] Various methods have been used to measure MSV, including the ellipsoid formula, which was utilized by Değermenci et al.[18] They found that MSV was not related to age. Our study yielded different results, possibly due to the use of a different volume measurement method. However, because the maxillary sinus is a complex anatomical structure with no uniform boundary, these measurements may differ from true values.

CBCT is superior to CT in a number of ways, including fewer metal artifacts, faster scan times, and the capacity to examine in the axial, coronal, and sagittal planes using 3D medical imaging software. Furthermore, CBCT is the favoured imaging modality in our study because it is more accessible, less expensive, and easier to utilize in a clinical context. The paranasal sinuses, nasoseptal flap measurements, and middle ear anatomy are frequently imaged with CBCT. CBCT can't see soft tissues, requires X-rays, and exposes patients to greater radiation doses than intraoral radiography, among other drawbacks.[21]

Comparison among two different software's

There are numerous third-party software applications that perform 3D segmentation on DICOM files[22]. Some examples include ON DEMAND3D, ITK-SNAP, MIMICS, and slicer 3D. Although there are very few studies comparing the accuracy and ease of handling these software applications in relation to dental structures, it is evident from the feedback gathered from various operators that ITK-SNAP and MIMICS are the two most widely used platforms for medical image segmentation and processing.[23,24]

There is a plethora of software available for analysing DICOM files , mostly include semi-automatic segmentation tools. Some free-source entities are accessible online. Many of these options were developed in a university setting or by small research groups, which may explain why dental clinicians are not always aware of them. In the present study, we tested one free-source software (ITK-SNAP) and one licensed version (MIMICS) specifically designed for volumetric analysis of the sinus.[25,26]

ITK-SNAP is a user-friendly, straightforward segmentation and registration toolkit that allows for regional and boundary-based segmentation of different anatomical structures scanned with various imaging modalities, including CT, MRI, and CBCT

Table 2: Independent t test on the accuracy of sinus volumes calculated among ITK-SNAP and MIMICS.

Group		N	Mean	Std. Deviation	p-value
Maxillary sinus volume	MIMICS	21	24247.81	6846.90	0.19
	ITK-SNAP	21	23113.33	6690.50	

Table 3: correlation statistics among the overall efficiency between ITK-SNAP and MIMICS.

		ITK-SNAP
Maxillary sinus volume MIMICS	Pearson Correlation	.798**
	Sig. (2-tailed)	.000
	N	21

Table 4: Schematic overview of technical differences between ITK-SNAP & MIMICS softwares

Category	Itk snap	Mimics
Purpose and usage	Primarily used for segmentation of 3D and 4D biomedical images. It is ideal for researchers and clinicians who need a free, open-source tool for detailed image segmentation	A commercial software used for converting 2D medical image data into 3D models. It is widely used in medical research, surgical planning, and custom implant design
Key features	**Semi-Automatic Segmentation**: Uses active contour methods (snakes). **Manual Segmentation**: Allows manual delineation in three orthogonal planes. **Image Navigation**: Linked cursor for seamless 3D navigation. **Support for Multiple Formats**: Compatible with NIfTI, DICOM, and other formats[1]. **User-Friendly Interface**: Modern graphical user interface	**Image Segmentation**: Advanced tools for segmenting anatomical structures. **3D Model Generation**: Converts segmented images into 3D models. **Measurement and Analysis**: Tools for measuring and analyzing anatomical structures. **Integration with CAD**: Export 3D models to CAD software for further design and analysis. **Simulation and Planning**: Used for pre-surgical planning and simulation
Cost	Free and open source	Commercial software, requires a license
Community & support	Designed to be user-friendly with a focus on ease of use. It has a modern interface and is relatively easy to learn	Also user-friendly but may require more training due to its extensive features and capabilities
applications	Supported by a community of researchers and developers. Extensive documentation and tutorials are available online[1].	Provides professional support and training. Extensive resources, including tutorials and user guides, are available

(figure 3) . This user-guided interface interactively guides the segmentation process, which can be performed manually or semi-automatically. Some literature suggests competitive results in the accuracy of brain tumour segmentation using ITK-SNAP.27 Additionally, ITK-SNAP is open-source and freely available for non-commercial and academic purposes, and its results are statistically significant and reproducible.

MIMICS software has many advantages and is preferred for analysing data of this nature.[28] Although it is not open source, many researchers and clinicians use it for various applications, including orthognathic surgery planning and maxillofacial reconstruction. (figure 2)

The present results indicate that there were no significant differences in the volume reconstruction of the sinus between ITK-SNAP & MIMICS.[29,30] In this investigation, the primary factors that might lead to variations in segmentation were operator variability as a random error and the threshold selection method as a systematic error. To control and limit these variables, the image scans used in the study were acquired using the same CBCT machine with the same acquisition parameters. This way, all variables influencing the precision of the 3D model rendering before the segmentation process were controlled.

The software algorithm, the thickness and level of calcification or cortication of the bone structure, and the spatial and contrast resolution of the scan all affect the semi-automated segmentation process.30 In light of the current findings, threshold-based seed points may not encompass hypodense voxels in this region, making it plausible that software based on the growing region algorithm (Slicer 3D, ITK-SNAP) may have trouble effectively recognizing boundaries.

While ITK-SNAP is a powerful tool, it has some limitations, such as assigning a single label to each pixel in the grayscale image, making the sub-voxel accuracy of the sinus boundaries difficult to segment, and lacking fully automated functionality.[31] However, it is designed to mimic commercial medical modelling software developed by Materialize, which is specifically designed for medicaland reconstructive image processing. It is more compatible with manual segmentation processes, allowing users to create 3D models from medical image data and perform precise measurements of volumes within anatomical structures such as the maxillary sinus. Studies have shown that it can produce comparable 3D models.[32]

Manual segmentation provides many methods. First, because of the operator's manual adjustments and anatomical understanding, it enables the detection of areas with poor bone density or lacking clearly defined boundaries. According to research[33], this is the reason why hand segmentation is regarded as the gold standard in situations when there are no true anatomic structures or laser scanning techniques available. Second, the operator's borders could not line up, which would change how the surface is shown. It may be inferred from the current research and prior data[34] that manual segmentation is very time-consuming and only reliable when carried out by a specialist. While there's currently not enough data to support the precise determination of a maxillary sinus region using semi-automated techniques, the process is dependable and faster than using a human approach. Therefore, from a clinical standpoint, in order to overcome the segmentation accuracy and time management issues, operators who require a precise definition of antral boundaries but lack the requisite technical skills in 3D imaging should seek assistance from companies that specialize in 3D imaging technology.

Limitations

The intra-observer and inter-observer accuracies, which are essential for getting over semi-automatic segmentation's two primary drawbacks—its operator dependence and time-consuming nature—were not assessed in this work. In contrast to earlier techniques that used generic hand-crafted features, recent applications of deep learning paradigm have shown very promising results in automated segmentation of anatomical structures from CBCT. Nevertheless, further research is required to address this new open scenario.

Conclusions

In summary, our study highlights that 3D computer-aided technology enables precise age and gender analysis by assessing sinus volumes. The ITK-SNAP program, recommended for measuring and segmenting CBCT scans, has proven to be a reliable and user-friendly semiautomatic tool, essential for our results. It is crucial to evaluate specific needs and select appropriate tools when addressing medical image segmentation tasks involving similar entities. This study demonstrates that open-source solutions can be both cost-effective and dependable. This technology facilitates comparative volume analysis among individuals, assessment of changes over time, and exploration of age- and gender-related variations.

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