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HEAD & NECK

Three-dimensional evaluation of maxillary sinus volume in different age and sex groups using CBCT

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Abstract

Aim Sinus maxillaris is an important anatomical formation in many branches of dentistry due to its proximity to the field of work. Various methods have been used in literature to measure the maxillary sinus volume (MSV) such as cadavers, stereology, two-dimensional conventional radiographs, computed tomography (CT), magnetic resonance imaging (MRI). The aim of this study is to evaluate the change of maxillary sinus volume according to age and gender with MIMICS 19.0 (Materialise HQ Technologielaan, Leuven, Belgium) which is one of three-dimensional modeling software.

Materials and methods This study was performed in 200 patients selected by a retrospective review of the archives of the Dicle University, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology. Patients were divided into five age groups (18–24 years, 25–34 years, 35–44 years, 45–54 years, and ≥ 55 years) and by sex. Cone-beam computed tomography (CBCT) images of the patients were transferred to the MIMICS software and the 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 higher than females.

Conclusion Consequently, maxillary sinus volume measurements can be made on CT, CBCT, MRI scans using reconstruction software.

Keywords Maxillary sinus volume · Cone-beam computed tomography · Third party software

Introduction

The success of treating sinonasal disorders the comprehensive knowledge and the proper visualiziation of the anatomic conditions of the osteomeatal complex and the paranasal sinuses is crutial in head and neck surgery, especially in otolaryngology, skull base surgery and maxillofacial surgery [1, 2].

The maxillary sinuses are of great interest to dentists because of their proximity to the area in which dentist's work. Knowledge of the maxillary sinus anatomy is valuable to prevent possible complications in maxillofacial surgery, and in the preoperative evaluation of dental implant treatment, estimation of the size of graft required for a sinus lift, and orthodontic mini-implant treatment. Besides dentistry, in forensic medicine, the maxillary sinus can be used for sex determination in cases in which the whole body cannot be found [3–7].

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Various methods have been used in published studies to measure the maxillary sinus volume (MSV). These methods include the injection of various materials into the maxillary sinus, stereology, and use of the ellipsoid formula [7–11].

In recent years, volume measurement using programs that allow segmentation and modeling based on semi-automatic processing of computed tomography (CT) and magnetic resonance (MR) images has become possible. These methods are compatible with three-dimensional (3D) imaging techniques and enable morphometric measurement. The programs allow the segmentation of structures using Hounsfield units; thus, the placement of dental implants and prostheses can be planned preoperatively using images that overlap those depicting patients' anatomy. In addition, an anatomically complex structure can be separated from neighboring structures, a 3D model can be created, the area and volume of the separated structure can be measured, and the density of the tissues can be compared [12]. CT modality is widely used as the "gold standard" for paranasal sinus imaging [13].

Cone-beam computed tomography (CBCT) is a technique that has been proposed for maxillofacial imaging during the last decade and was first reported on in the literature by Mozzo et al. [14, 15]. A CBCT scan uses a different type of acquisition than CT. Rather than capturing an image as separate slices, as in CT, CBCT produces a cone-shaped X-ray beam that makes it possible to capture the image in a single shot. The resultant volume can be reformatted to provide multiple reconstructed images perspectives such as sagittal, coronal and axial that are similar to traditional MDCT images [16]. CBCT employs isotropic voxels, which enables the investigation of cross-dimensions and transitions between planes other than orthogonal planes. Curved structures, such as dental arches can also be examined using isotropic voxels [17]. In addition, costs are lower than those for CT [16].

CBCT can also offers an advantage of a lower radiation dose than CT especially in limited field of view (FOV) and particularly, evaluating maxillary sinuses [18]. It should be stated that CBCT can involve a radiation dose of between 25 and 35 μSv in a limited FOV, whereas a full head CBCT imaging can involve a dose ranging from 68 to 1073 μSv which is similar to CT in the highest dose. The excess risk is equivalent to between a few days and several weeks of the average per capita background dose [19].

The growing demand in CBCT imaging brings the possibility of importing and exporting individualized, overlapfree reconstructions and DICOM data to and from other applications especially fıor maxillofacial and paranasal sinus imaging. So far, in the English literature, to the best of our knowledge there is a limited information of comparative evaluation of the maxillofacial and head and neck structures using CBCT imaging.

Hence, it was considered worthwhile to compare the maxillary sinus volumes according to age and sex obtained by semiautomatic mode of an imaging software (MIMICS 19.0 3D modeling software; Materialise HQ Technologielaan, Leuven, Belgium) using CBCT image sequences.

Materials and methods

This study involved the use of CBCT images of patients referred for various reasons to the Dicle University, Faculty of Dentistry, Department of Oral and Maxillofacial Radiology between 2009 and 2016. Two thousand images in the radiology archive were reviewed retrospectively. The Ethics Committee of the Dicle University Dentistry Faculty approved this study.

The indications of the patients who had undergone CBCT imaging for dental implant surgery, orthognathic surgery, impacted third molar surgery, cyst or tumor of dental structures but not affected the maxillary sinus. Patients selected for this study had no pathology (fracture, inflammation, residual root, overflowing endodontic material, or condition requiring surgery) or trauma that affected the anatomy or integrity of the maxillary sinuses. Patients were aged > 18 years and had all permanent teeth, excluding the third molars. Patients with no missing teeth in the maxillary and mandibular posterior regions were selected.

All CBCT images regarding orthognathic surgery were taken before surgery and any orthodontic treatment. The patients that had bracelets and undergoing the orthodontic treatment were excluded. Moreover, patients with evidence of bone disease (especially osteoporosis); relevant drug consumption; skeletal asymmetries, congenital disorders, anamnesis of surgical procedures or any pathological disorders involving the maxillary sinuses or the sphenoid sinus; syndromic patients. In the final study group, all patients were free of any disease and all paranasal sinuses were empty cavities without any pathological conditions.

The CBCT images of 200 patients (114 females and 86 males) who met the study criteria were included in the study. Patients were divided into five age groups (18–24 years [$n = 35$], 25–34 years [$n = 65$], 35–44 years [$n = 50$], 45–54 years [$n = 30$], and ≥ 55 years [$n = 20$]) and by sex. The right and left MSVs of each patient were calculated separately; in total, 400 MSVs were recorded.

All images were acquired using an I-CAT Vision system (Imaging Sciences International, Hatfield, PA, USA). The scanning parameters were as follows: 120 kVp, 5 mA, 8.9-s acquisition time, 0.3-mm-thick axial slice and isotropic voxel size, and 16 × 13-cm image area. All images were recorded in the Digital Imaging and Communications in Medicine format. The entire data were constituted of 0.3-mm-thick axial slices as single DICOM files. Axial images were exported with a 512 × 512 matrix as a single frame per DICOM file.

The CBCT images were transferred to a computer, where the MSVs were measured using MIMICS 19.0 software. Thresholding was applied with a minimum limit of − 1024 HU and a maximum of − 526 HU [20]. The maxillary sinus was cropped using the software's "edit masks" tool along the following borders: around the bone structure and the narrowest space of the ostium between the infundibulum and processus uncinatus [21]. Next, the connection with the outer air was cropped slice by slice using the segmentation tools. Finally, the "region growing" tool, which enables splitting of the segmentation created by thresholding into several objects and the removal of floating pixels, was applied. The MSVs were calculated using the software's "calculate 3D" tool.

Statistical analysis

Statistical analyses were performed using SPSS 17.0 software (SPSS Inc., Chicago, IL, USA), and the data are expressed as means ± standard deviations. The same observer repeated measurements at a 1-month interval. To assess intra-observer reliability, the Wilcoxon matched-pairs signed rank test was used for repeat measurements. The conformity of the parameters to normal distribution was investigated by Kolmogorov–Smirnov test. As all data were distributed normally so student's *t* test that the mean of two independent groups 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. Within-group comparisons were performed using Tukey's honestly significant difference test. *P* values < 0.05 were considered to indicate statistical significance.

Results

Repeated CBCT evaluation and measurements indicated no significant intra-observer difference for observer ($p > 0.05$). Overall intra-observer consistency for the examiner was rated at 84.2% and 90.6%, between the two evaluations and measurements, respectively. All measurements were found to be highly reproducible for both observers and no significant difference was obtained from two measurements of the observers ($p > 0.05$).

The average bilateral MSV was 29.09 ± 7.829 cm^3 (range 11.10–51.97 cm^3). The mean right and left MSVs were 14.49 ± 3.998 cm^3 and 14.59 ± 3.984 cm^3, respectively ($p > 0.05$). There was no statistically significant difference between right and left sinus volume.

The mean MSVs in women and men were 27.18 ± 6.778 cm^3 and 31.62 ± 8.430 cm^3, respectively. The MSV was significantly greater in males than in females ($p < 0.001$) (Table 1). The mean MSVs for each age group is shown in Fig. 1. The MSV differed significantly among age groups ($p < 0.05$). The MSV decreased with increasing age; it was significantly greater among patients aged 18–24 years than among all patients aged ≥ 35 years. A significant difference was observed between two age groups ($p < 0.001$; Table 2). Comparison of the MSVs of males and females in each age group is shown in Table 1. Only women in the 18–24-year-old group had smaller MSVs than did their male counterparts ($p < 0.05$). In the other age groups, MSVs were lesser among women than among men, but these differences were not significant.

Discussion

Previous studies have also investigated volumetric changes in the maxillary sinus; relationships with tooth position; and changes induced by orthodontic treatment, septum deviation, and sinus pathologies, in addition to examining differences in maxillary sinus dimensions and anatomy according to age, sex, and race [21–27]. Motro, examined the effect of rapid maxillary expansion therapy on the MSV [21]. Cho

Table 1 Comparison of the maxillary sinus volumes of males and females in each age group (cm^3)

Gender	Parameters	Patients (*n*)	Average MSVs (cm^3)	Std. deviation	*p* value
Female	Right MSV	114	13.42	3.436	> 0.05
	Left MSV	114	13.75	3.507	> 0.05
	18–24 years	16	**29.52**	**6.329**	**< 0.05***
	25–34 years	40	29.35	5.866	> 0.05
	35–44 years	30	26.09	7.21	> 0.05
	45–54 years	18	23.89	7.069	> 0.05
	≥ 55 years	10	24.05	5.647	> 0.05
Male	Right MSV	86	**15.92**	**4.259**	**< 0.001***
	Left MSV	86	**15.7**	**4.316**	**< 0.001***
	18–24 years	19	**37.01**	**7.585**	**< 0.05***
	25–34 years	25	32.75	8.664	> 0.05
	35–44 years	20	29.96	8.79	> 0.05
	45–54 years	12	27.91	5.809	> 0.05
	≥ 55 years	10	26.42	5.662	> 0.05

*Significant differences are indicated in bold

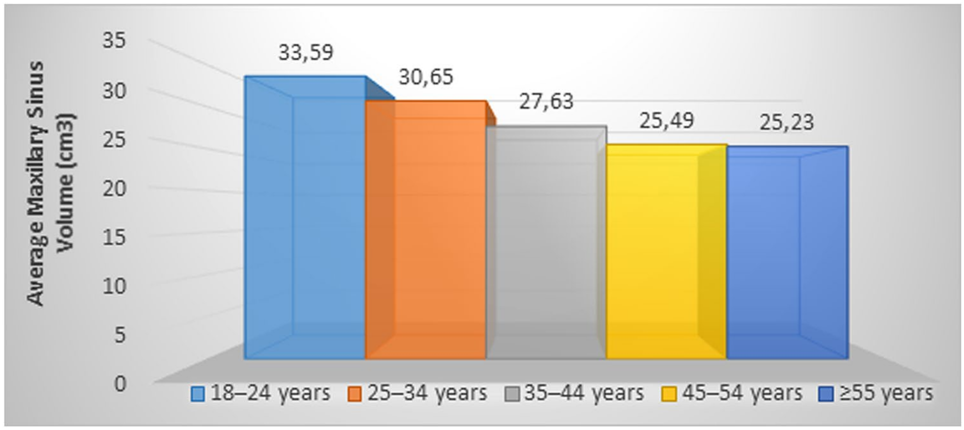

Fig. 1 Maxillary sinus volumes according to age group (cm^3)

Table 2 Comparison of the maxillary sinus volume between age groups

	Age groups (years)	Patients (*n*)	Average maxillary sinus volume (cm^3)	Std. deviation	*p* value
18–24 years	25–34	65	30.65	7.203	0.317
	35–44	50	27.63	8.023	**0.003***
	45–54	30	25.49	6.791	**0***
	≥ 55	20	25.23	5.636	**0.001***
25–34 years	18–24	35	33.59	7.902	0.317
	35–44	50	27.63	8.023	0.191
	45–54	30	25.49	6.791	**0.015***
	≥ 55	20	25.23	5.636	**0.035***
35–44 years	18–24	35	33.59	7.902	**0.003***
	25–34	65	30.65	7.203	0.191
	45–54	30	25.49	6.791	0.716
	≥ 55	20	25.23	5.636	0.73
45–54 years	18–24	35	33.59	7.902	**0***
	25–34	65	30.65	7.203	**0.015***
	35–44	50	27.63	8.023	0.716
	≥ 55	20	25.23	5.636	1
≥ 55 years	18–24	35	33.59	7.902	**0.001***
	25–34	65	30.65	7.203	**0.035***
	35–44	50	27.63	8.023	0.73
	45–54	30	25.49	6.791	1
Total		200	29.09	7.829	

*Significant differences are indicated in bold

et al. examined differences in the MSV according to patients' dentition status [22]. Möhlhenrich et al. examined sex differences in the MSV [23]. Park et al. studied the paranasal sinus volumes of Asian patients [27]. Orhan et al. investigated the effect of septum deviation on the MSV [28]. In our study, differences in the MSVs of adult patients according to age and sex were examined using the MIMICS program.

Published studies of the MSV have produced different results [29–31]. Aksoy, found no significant difference between the right and left MSVs, and reported that the MSV was significantly greater in males than in females [32]. This result corroborates our results (Table 3). Demir et al. also found no significant difference between the right and left MSVs, and reported that the right MSV differed significantly between males and females [33]. This difference is thought to be due to sexual dimorphism.

Prabhat et al. reported that the MSV was significantly greater in males than in females and that the right MSV was greater than the left MSV [34]. In contrast, our study revealed no significant difference between the right and left MSVs (Table 3).

Table 3 Comparison of the results with select data from the literature

	Gender	MSV (cm^3)	
		Right	Left
Aksoy [29]	Female	14.08	14.15
	Male	15.79	16.45
Demir et al. [30]	Female	14.17	14.61
	Male	16.32	16.46
Prabhat et al. [31]	Female	11.61	10.95
	Male	16.63	15.19
In our study	Female	13.42	13.75
	Male	15.92	15.7

Takahashi et al. reported mean bilateral MSVs of 31.3 cm^3 overall, 29.6 cm^3 in females, and 32.9 cm^3 in males. In addition, they found that the bilateral MSV decreased with age, with no significant difference between males and females. This finding can be explained by the reduced sex difference due to decreasing MSV with increasing age [30].

Jun et al. stated that the development of the maxillary sinus continues until the second and third decades of life in females and males, respectively, with an age-associated decline in volume occurring after development has been completed. They stated that the MSV is significantly greater in males than in females during the developmental period. Thereafter, they reported no significant difference between males and females within age groups [31]. Our study yielded similar results (Table 1). Thus, maxillary sinus growth and development may be completed later in life in males compared with females.

Ariji et al. reported that the MSV increased up to the age of 20 years and then decreased. In addition, they found no significant difference between the right and left MSVs or between sexes [29]. The lack of a significant difference between the right and left MSVs is comparable to our findings, but we observed a significant difference between sexes. Similar to that study, we found the greatest MSV in the 18–24-year-old group and lesser MSVs in older patients. Thus, the continuation of growth and development of the facial bones could lead to an increase in the MSV. Different methods have been used to measure the MSV. Sahlstrand-Johnson et al. calculated the MSV using the ellipsoid formula and found that the MSV was not related to age [35]. Our study yielded a different result, which can be attributed to the use of different volume measurement methods. The ellipsoid method involves measurement of the widest, highest, and deepest sections of the maxillary sinus. However, because the maxillary sinus is a complex anatomical structure with no uniform boundary, these measurements may differ from the true values. Anagnostopoulou et al. found that the left and right MSVs of skulls were 11.9 cm^3 and 11.6 cm^3, respectively [36]. The disadvantages of this method are that measurements cannot be repeated, access to some paranasal sinuses is difficult, the injection of substances is difficult, and measurements obtained are greater than true values due to soft-tissue loss [7, 9].

Compared with CT, CBCT has fewer metal artifacts and a shorter time of shot, and it can be used with 3D medical imaging software, enabling the examination of obtained images in the axial, coronal, and sagittal planes. In addition, CBCT is less expensive, easier to use in the clinic, and accessible; thus, this modality is preferred, as in our study [37–39]. Cone-beam computed tomography (CBCT) is a frequently used device for imaging paranasal sinuses, nasoseptal flap dimensions, and imaging of the middle ear anatomy [40–42]. The limitations of CBCT include such as the inability to visualize soft tissues, working with X-rays and the delivery of higher radiation doses than with intraoral radiographs [43].

In our study, a 0.3-mm^3 voxel size was used. Torres et al. reported no significant difference among voxel sizes of 0.2 mm^3, 0.3 mm^3, and 0.4 mm^3 for linear bone measurement [44]. Sherrad et al. reported no significant difference among these voxel sizes in the measurement of root canal length [45].

Many advantages of the MIMICS software have been reported [46, 47], and this software is preferred for data analysis of this nature. Weissheimer et al. compared the MIMICS, OsiriX, Dolphin3D, InVivo Dental, and Ondemand3D 3D modeling programs, and found that MIMICS had the least error sharing (0.2%) [46]. Thayyil et al. evaluated the sensitivity of the MIMICS program using MR images of 12 kidneys, hearts, and livers taken from various animals. They reported high degrees of correlation between the actual organ volumes and those measured with the software [47].

Moreover, Szabo et al. in a recent study compared the paranasal sinus volumes that obtained by manual and semi-automatic imaging software programs using both CT and CBCT imaging. They concluded that CBCT images provide reliable volumetric information from which the artificial organ construction might be dependable, which may aid the guidance of the operator prior to or during the intervention [18].

Conclusions

With the development of technology, software programs that perform three-dimensional modeling have been introduced in the measurement of maxillary sinus volume. With the data in our study, we believe that elaboration of the studies related to maxillary sinus volume in the future by using these programs will contribute to the scientific literature.

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Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical statements The Ethics Committee of the Dicle University Dentistry Faculty approved this retrospective study. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions. Informed consent was obtained from all patients for being included in the study.

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