doi: 10.30934/kusbed.836910 **e-ISSN:** 2149-8571

Kocaeli Üniversitesi Sağlık Bilimleri Dergisi

Özgün Araştırma / Original Article

http://dergipark.gov.tr/kusbed

COMPARISON OF MANUAL AND SEMIAUTOMATIC SEGMENTATION METHODS FOR CALCULATING FRONTAL AND SPHENOID SINUS AREA AND VOLUME USING OF COMPUTED TOMOGRAPHY

FRONTAL VE SFENOİD SİNUS ALAN VE HACMİNİN MANUEL VE YARI OTOMATİK SEGMENTASYON MODÜLÜ KULLANILARAK BİLGİSAYARLI TOMOGRAFİDE İNCELENMESİ

Ceren Aktuna Belgin[1*], Gözde Serindere[1]

[1]Hatay Mustafa Kemal University, Faculty of Dentistry, Department of Dentomaxillofacial Radiology, 31060 Hatay, Turkey

ORCID iD: Ceren Aktuna Belgin: 0000-0001-7780-3395; Gözde Serintepe: 0000-0001-7439-3554

***Sorumlu Yazar / Corresponding Author:** Ceren Aktuna Belgin **e-posta / e-mail:** dtcaktuna@gmail.com

Geliş Tarihi / Received: 07.12.2020 **Kabul Tarihi / Accepted:** 31.03.2021 **Yayım Tarihi / Published:** 31.10.2021

Abstract

Objective: To compare the effectiveness of the manual and semi-automatic segmentation modules of the third-generation software used in computed tomography (CT) images in calculating frontal sinus (FS) and sphenoid sinus (SS) areas and volumes.
Methods: CT images of 200 patients (96 female, 104 male) between the ages of 19 and 73 years (mean 37.38 ± 16.32 years) were randomly selected. Volume and area of FS and SS were segmented manually and semi-automatically using InVesalius 3.1.1 software (CTI, Campinas, São Paulo, Brazil).
Results: There was a statistically significant difference was found the main SS area in manual mode and semi-automatic mode as 4.80 ± 1.86 cm^2 and 4.84 ± 1.83 cm^2, respectively. The main SS volumes were in manual mode and semi-automatic mode as 8.44 ± 3.55 cm^3 and 9.62 ± 3.21 cm^3, respectively. The main FS volumes were in manual mode and semi-automatic mode as 5.32 ± 2.04 cm^3 and 6.65 ± 2.70 cm^3, respectively. There was a statistically significant difference was found between manual mode and semi-automatic mode in volume calculation (p<0.05).
Conclusion: It was seen that the values measured in both segmentations are close to those presented in the mean literature data, however, when using the semi-automatic segmentation module, it should be ensured that the formations other than the structure to be evaluated are not included in the measurement.

Keywords: *Manual segmentation, semi-automatic segmentation, frontal sinus, sphenoid sinus, computed tomography*.

Öz

Amaç: Frontal sinus (FS) ve sfenoid sinus (SS) alan ve hacimlerinin ölçümlerinde üçüncü jenerasyon yazılımların manuel ve yarı otomatik segmantesyon modüllerinin etkinliğinin bilgisayarlı tomografi (BT) görüntüleri kullanılarak karşılaştırılmasıdır.
Yöntem: Yaşları 19-73 arasında değişen (ortalama 37,38 ± 16,32 yıl) 200 hastaya (96 kadın, 104 erkek) ait BT görüntüleri rastgele seçilmiştir. FS ve SS alan ve hacimleri InVesalius 3.1.1 (CTI, Campinas, São Paulo, Brazil) yazılımın manuel ve yarı otomatik segmentasyon modülleri kullanılarak ölçülmüştür.
Bulgular Manuel (4,80 ± 1,86 cm^2) ve yarı otomatik (4,84 ± 1,83 cm^2) segmentasyon modlarındaki SS alan ölçümleri arasında istatistiksel olarak anlamlı bir fark bulunmuştur (p<0,05). SS hacmi manuel ve yarı otomatik segmantasyon modüllerinde sırasıyla 8,44 ± 3,55 cm^3 ve 9,62 ± 3,21 cm^3 olarak, FS hacmi ise manuel ve yarı otomatik segmantasyon modüllerinde sırasıyla 5,32 ± 2,04 cm^3 ve 6,65 ± 2,70 cm^3 olarak hesaplanmıştır. Hacim hesaplamaları arasında her iki modül arasında istatistiksel olarak anlamlı bir fark bulunmuştur (p<0,05).
Sonuç: Her iki segmentasyon modülünde elde edilen verilerin literatürde belirtilen verilere yakın olduğu görülmüştür. Ancak yarı otomatik segmentasyon modülünde değerlendirilecek yapı dışında kalan anatomik oluşumların ölçümlere dahil olmadığından emin olunması gerekmektedir.

Anahtar Kelimeler: *Manuel segmantasyon, yarı-otomatik segmentasyon, frontal sinus, sfenoid sinus, bilgisayarlı tomografi.*

Introduction

The frontal sinus (FS) is an irregularly shaped pneumatic cavity in the frontal bone, deep within the superciliary arch.[1] Although it is difficult to find in the literature an accepted standard method for personal identification, many studies have found success in the use of FS examinations.[2,3] Indeed, it has been scientifically demonstrated that each individual has distinctive FS that is not affected by strains.[4] Today, the identification of organs that cannot be identified by examining the FS is a legal technique used when pre-registers are available. Such identification can be presented as evidence in a court of law.[1,5] The highly variable sphenoid sinus (SS), which is located in the centre of the cranial base[6], is adjacent to important structures such as the optic nerve, the cavernous sinus, and the pituitary gland. Only a thin bone wall separates it from the neurocranium and viscerocranium.[7,8]

Radiographs play an important role in the preoperative evaluation of paranasal anatomical structures. Computed tomography (CT), which is considered to be the 'gold standard' method, is often used as an adjunct to clinical research for localizing and measuring the size of pathological lesions of paranasal sinuses, as well as to confirm anatomical markers and diagnosis.[9,10] However, studies in the anthropological literature have shown that the use of CT scans for morphometric studies of the paranasal sinuses is easy and reliable for antemortem/post-mortem comparison.[11,12]

Developments in new generation software have made it possible to separate complex anatomical structures from each other and to make volume measurements. The third-generation software that divides the nasal cavity into segments performs automatic segmentation of the airway based on the global threshold value. This method is based on setting a density range (grey threshold) so that voxels outside the density range are considered zero. Although this provides a fast segmentation, it can also produce false segmentations.[13] With its dependence on the grey threshold, automatic segmentation may lead to the mistaken addition of air-like (thin mucous tissues or secretions, etc.) or air-identical (noise, etc.) values to the segmentation.[14]

While there are publications in the literature in which the paranasal sinus area and volume are calculated with third-generation software programs[15-17], very few studies compare the results obtained using the different modules of these programs.[18-19] Therefore, we think that this study, in which we aim to compare the effectiveness of the manual and semi-automatic segmentation modules of the third-generation software used in computed tomography images in calculating FS and SS areas and volumes, will contribute to the literature.

Methods

This retrospective study was approved by the Local Ethics Committee of the xxx University (Decision No: 65, Date: 13/02/2020) and the study protocol was conducted in accordance with the principles set out in the Declaration of Helsinki. Three hundred CT images were requested from patients who had applied to our faculty's Dentomaxillofacial Radiology Department for a variety of reasons (temporomandibular joint disorders, orthodontic treatment, etc.) between 2017-2019. CT images involving any of the following were excluded from the study: artefacts preventing diagnostic evaluation, patients with specific bone diseases (osteoporosis etc.), disorders of skeletal asymmetry or trauma, images showing the effects of any surgery or other lesion affecting the paranasal sinuses, those with congenital disorders, and syndromic patients. The researchers showed no gender preference in selecting study participants. CT images of 200 patients (96 female, 104 male) between the ages of 19 and 73 years (mean 37.38 ± 16.32 years) who were excluded from these criteria were randomly selected. All CT images were taken with a 64-row MDCT scanner (Toshiba Aquilion, Toshiba Medical Systems, Otawara, Japan) in accordance with the routine maxillofacial radiography format.

After recording the demographic information of the patients—including age and gender—the threshold value was selected (minimum -1024 and maximum –526 Hounsfield Units) for marking the paranasal sinuses and airways.[20] Based on the studies of Szabo et al.[21], both the FS and SS were manually segmented from the airways and other connections in each section, where they were seen with the manual segmentation module of the software. After checking the accuracy of the selected region in all planes, the areas and volumes of each sinus were calculated separately (Figure 1). Secondly, a new mask was created for new calculating using semi-automatic segmentation. The program's 'Watershed' module is used for semi-automatic segmentation. For measurements made on the image of the same patient, the areas to be included in the measurement (the segmentation mask) were marked in green, the boundaries of the structure to be measured (background markers) were marked in red, and the sinuses were separated from the adjacent anatomical structures and the airway (Figure 2). The 'Gaussian sigma' filter was then applied. Gaussian sigma is a parameter used in the smoothing algorithm to eliminate noise and to obtain better results before image segmentation. The 'Watershed' is normally applied only in one slice, not in the whole image. After adding the markers it is possible to apply the 'Watershed' to the whole image by clicking the 'Expand Watershed to 3D' button. Finally, after checking the accuracy of the segmentation performed by the software in all planes, volume and area measurements were made. The overlapping of the FS and SS volumes created by semi-automatic and manual segmentation is shown in Figure 3. InVesalius 3.1.1 software (CTI, Campinas, São Paulo, Brazil) was used for all measurements.

All image evaluation and measurement procedures were performed by two dentomaxillofacial radiologists who have calibrated with six years and five years of clinical experience. To ensure standardization of all measurements and to rule out differences in image resolution, the same laptop (Dell Inc., Round Rock, TX, USA) was used and image manipulation using development tools were not allowed. Repeated measurements were made to ensure validity. To quantify the intraobserver agreement, 50 images were randomly selected from the sample and re-evaluated by the observers two weeks later. The average values of these measurements were used for statistical analysis.

Statistical analysis

All statistical analyses were performed with SPSS (SPSS Inc., Chicago, IL, USA) version 25. The Pearson correlation test (for the relationship between the two quantitative variables), an independent t-test (for differences between genders), and a paired t-test (for the difference between manual and semi-automatic modes) were used to analyse the data. Intraclass correlation (ICC) values were calculated for interobserver compliance. Differences were considered significant when $p < 0.05$.

Results

The ICC values indicated high reliability for the volume and area of both sinuses in manual mode (0.900) and excellent reliability for the volume and area of both sinuses in semi-automatic mode (0.960). General descriptive statistics of all quantitative variables and descriptive statistics of quantitative variables based on gender are shown in Tables 1 and 2, respectively.

There was no statistical significance found in the main FS area between manual mode (3.88 ± 1.60 cm^2) and semi-automatic mode (3.91 ± 1.58 cm^2) ($p>0.05$). On the other hand, a statistically significant difference was found between the main SS area in manual mode and semi-automatic mode, as 4.80 ± 1.86 cm^2 and 4.84 ± 1.83 cm^2, respectively ($p<0.05$).

The main SS volumes were, in manual mode and semi-automatic mode, 8.44 ± 3.55 cm^3 and 9.62 ± 3.21 cm^3, respectively. Also, the main FS volumes were, in manual mode and semi-automatic mode, 5.32 ± 2.04 cm^3 and 6.65 ± 2.70 cm^3, respectively. In volume calculation, statistical significance was found between manual mode and semi-automatic mode ($p<0.05$).

In both modules, the FS and SS volumes in men were statistically significantly higher than in women ($p<0.05$). Although there was no significant statistical difference, the FS and SS areas in both modules were higher in men ($p>0.05$). There was a significant difference between age and FS and SS volume and area in both modules. In both modules, both area and volume decrease as age increases ($p = 0.000$).

There was a strong correlation between both FS and SS volumes and areas in both modules ($p = 0.000$).

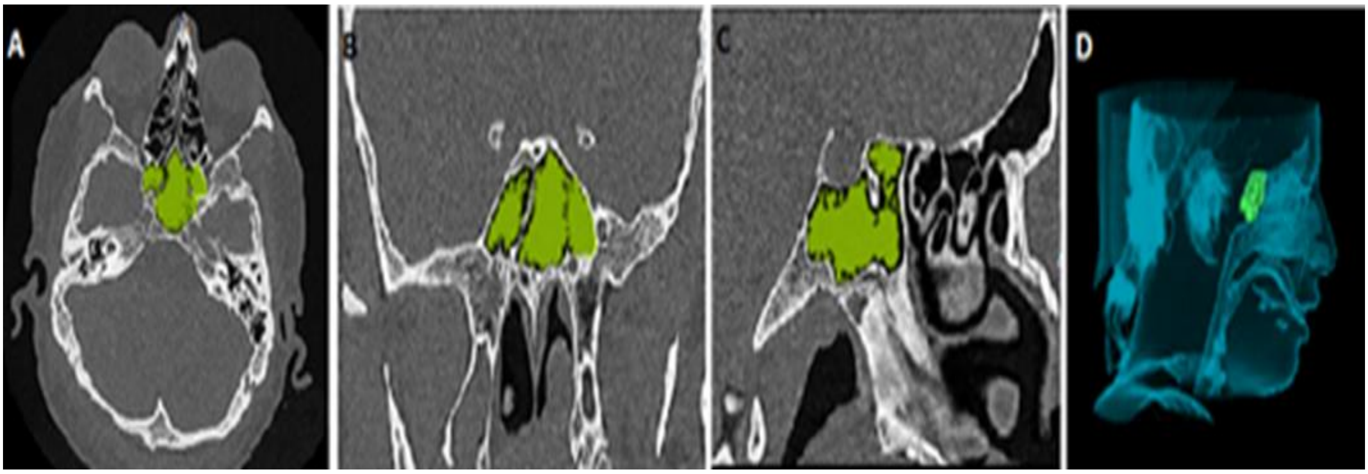

Fig. 1. Manual segmentation. A: Axial plan, B: Frontal plan, C: Sagittal plane. D: 3D view

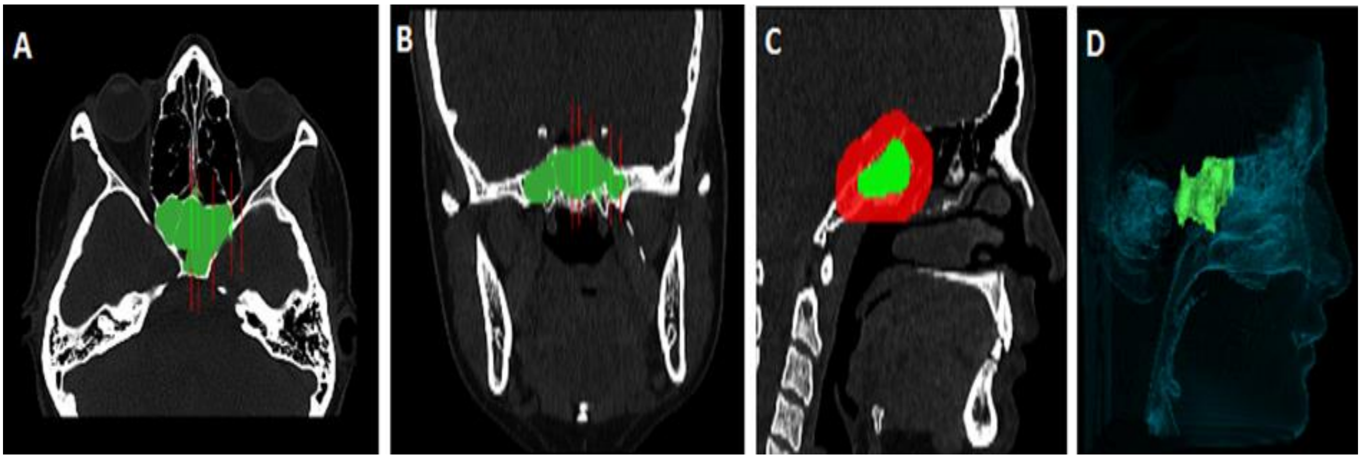

Fig. 2. Semi-automatic segmentation. A: Axial plan, B: Frontal plan, C: Sagittal plane. D: 3D view.

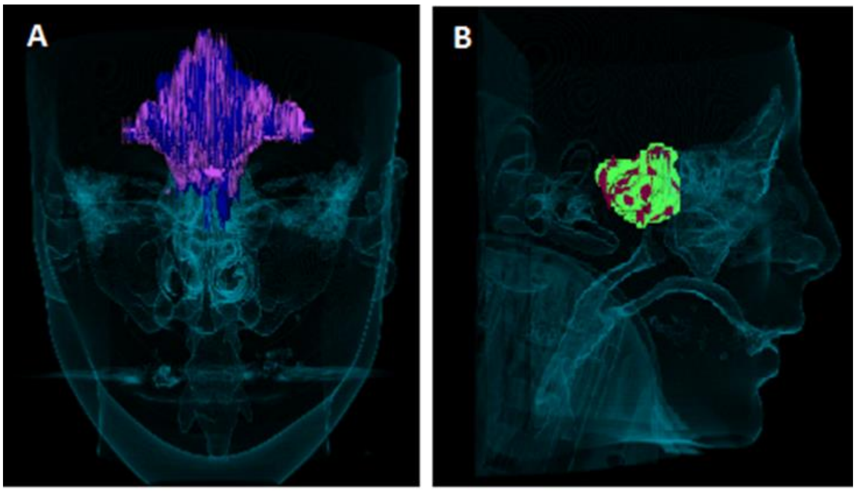

Fig. 3. A: The overlapping of frontal sinus volume created by semi-automatic and manual segmentation. Blue: manual segmentation, Purple: semi-automatic segmentation;
B: The overlapping of sphenoid sinus volume created by semi-automatic and manual segmentation. Green: Manual segmentation, Pink: semi-automatic segmentation.

Table 1. Comparison of Sphenoid Sinus Volume in the Literature

Reference	n	Methods	Sphenoid Sinus Volume		
			Female (Mean ± SD)	**Male (Mean ± SD)**	**Total (Mean ± SD)**
Karakas and Kavakli[16], 2005	91 CT (44 F, 47 M)	Cavalieri principle	6.00 ± 3.02 cm^3	6.83 ± 3.73 cm^3	6.43 ± 3.41 cm^3
Emirzeoglu *et al.*[12], 2007	77 CT (38 F, 39 M)	Cavalieri principle	6.1 ± 3.2 cm^3	7.7 ± 4.0 cm^3	13.6 ± 0.7 cm^3
Pirner *et al.*[13], 2009	50 CT (23 F, 24 M, 3 cadaver heads)	OpenGL software	9.6 ± 4.0 cm^3	13.3 ± 4.4 cm^3	11.2 ± 4.5 cm^3
Selcuk *et al.*[27], 2015	Ağrı City: 60 CT (25 F, 35 M)	The formula (a x b x c x 0.52)	6.00 ± 3.12 cm^3	7.03 ± 3.95 cm^3	6.35 ± 3.60 cm^3
	Antalya City: 55 CT (26 F, 29 M)		7.20 ± 3.93 cm^3	9.00 ± 4.39 cm^3	7.81 ± 4.34 cm^3
Cohen *et al.*[15], 2017	201 CT (100 F, 101M)	Volume Tracing in Advanced Vessel Analysis, Philips Healthcare, Cleveland, Ohio, USA	3.55 ± 1.73 cc	4.74 ± 2.06 cc	4.00 ± 1.99 cc
Ozer *et al.*[28], 2018	144 CT (55 F, 89 M)	OsiriX Foundation, Geneva, Switzerland	8.33 ± 3.41 cc	10.24 ± 4.50 cc	9.51 ± 4.24 cc
Aydemir *et al.*[29], 2019	99 CT+MRI (44 F, 55 M)	Sinus volume index (SVI) formula = ½. A × B × C.			7.54 ± 3.8 cm^3
In present study	200 CT (96F, 104M)	InVesalius 3.1.1 software (CTI, Campinas, São Paulo, Brazil)	Manual Mode: 7.77 ± 2.32 cm^3 Semi-automatic Mode: 9.30 ± 2.68 cm^3	Manual Mode: 10.06 ± 5.86 cm^3 Semi-automatic Mode: 9.92 ± 3.62 cm^3	Manual Mode: 8.44 ± 4.55 cm^3 Semi-automatic Mode: 9.62 ± 3.21 cm^3

Table 2. Comparison of Frontal Sinus Volume in the Literature

Reference	n	Methods	Frontal Sinus Volume		
			Female (Mean ± SD)	**Male (Mean ± SD)**	**Total (Mean ± SD)**
Karakas and Kavakli,[16] 2005	91 CT (44 F, 47 M)	Cavalieri principle	2.87 ± 2.29 cm^3	6.86 ± 4.83 cm^3	4.97 ± 4.31 cm^3
Emirzeoglu *et al.*[12], 2007	77 CT (38 F, 39 M)	Cavalieri principle	4.1 ± 2.9 cm^3	7.5 ± 4.3 cm^3	11.6 ± 0.8 cm^3
Pirner *et al.*[13], 2009	50 CT (23 F, 24 M, 3 cadaver)	OpenGL software	5.5 ± 3.5 cm^3	10.2 ± 6.2 cm^3	7.9 ± 5.5 cm^3
Yun *et al.*[30], 2011	68 CT (33 F, 35 M)	AW VolumeShare 2 (Ver. 8.4.3; GE Healthcare, Waukesha, WI) Lucion (Ver 1.2; Mevisys, Seoul, Korea)	8.23 ± 3.63 cm^3	8.54 ± 3.84 cm^3	8.39 ± 3.78 cm^3
Selcuk *et al.*[27], 2015	Ağrı City: 60 CT (25 F, 35 M)	The formula (a x b x c x 0.52)	3.09 ± 4.04 cm^3	5.40 ± 7.13 cm^3	3.76 ± 6.27 cm^3
	Antalya City: 55 CT (26 F, 29 M)		2.65 ± 4.32 cm^3	6.20 ± 5.82 cm^3	5.51 ± 5.43 cm^3
Michel *et al.*[31], 2015	69 CT (35 F, 34 M)	MIMICS 10.0 (Materialise HQ Technologielaan, Leuven, Belgium)	2.42 ± 1.71 cm^3 (right), 2.64 ± 2.02 cm^3 (left)	4.51 ± 3.09 cm^3 (right), 5.03 ± 3.27 cm^3 (left)	
Cohen *et al.*[15], 2017	201 CT (100 F, 101M)	Volume Tracing in Advanced Vessel Analysis, Philips Healthcare, Cleveland, Ohio, USA	3.21 ± 2.79 cc	3.74 ± 2.97 cc	2.92 ± 2.57 cc
Aydemir *et al.*[29], 2019	99 CT (44 F, 55 M)	Sinus volume index (SVI) formula = ½. A × B × C.			9.56 ± 7.1 cm^3
In present study	200 CT (94 F, 106M)	InVesalius 3.1.1 software (CTI, Campinas, São Paulo, Brazil).	Manual Mode: 4.94 ± 2.47 cm^3 Semi-automatic Mode: 6.34 ± 2.82 cm^3	Manual Mode: 6.73 ± 2.57 cm^3 Semi-automatic Mode: 6.93 ± 2.57 cm^3	Manual Mode: 5.32 ± 2.04 cm^3 Semi-automatic Mode: 6.65 ± 2.70 cm^3

Discussion

The literature frequently mentions the importance of FS measurements for the purpose of identification in forensic medicine[2,3], while the SS should be evaluated preoperatively due to its adjacency to critical anatomical structures such as the internal carotid artery and the optic nerve.[22] The SS reportedly reaches its mature size during adolescence (approximately 12-14 years old)[23], after which the area of aeration begins to decrease with ossification following spheno occipital synchondrosis.[24] It has been reported that the FS completes its development around the age of 19.[25] Our study included radiographs of persons over 19 years old whose FS and SS development were thought to be complete.
The use of visualization technologies and the three-dimensional analysis of medical images assists the surgeon in diagnosing pathologies and in the advanced, detailed surgical planning and simulation of a complex process which may involve, for example, a high degree of facial deformity or the integration of prosthetics. The third-generation InVesalius software, which performs analysis and segmentation of virtual anatomical models, enables the creation of physical models with the aid of rapid prototyping. The program allows users to create three-dimensional anatomical representations of patients from images obtained through CT or Magnetic Resonance Imaging.[26]
The literature contains very few studies that compare segmentation modules in third-generation programs capable of measuring volume. In a cone-beam CT images study with 10 patients, Alsufyani et al.[19] evaluated the accuracy of both manual and semi-automatic segmentation of the pharyngeal and nasal airways. In their results, they stated that semi-automatic segmentation of the pharyngeal and nasal airways using Segura software was found to be reliable, valid, and time efficient. Forst et al.[18], who analysed the reliability of a set of previously developed and proposed image segmentation protocols for 10 molar tooth volume measurements using cone-beam CT images, stated that automated segmentation with manual refinements had the greatest precision. Szabo et al.[21], used another software package to measure the volumes of the maxillary and sphenoid sinuses in both manual mode and semi-automatic mode. They found that the mean SS volumes were, in hand mode and semi-automatic mode, 4.74± 2.61 mm^3 and 3.10 ± 2.17mm^3, respectively. Consequently, they reported that measurement averages obtained by manual mode compared with the literature data were closer. In our study, the main SS volumes were, in hand mode and semi-automatic mode, 8.44 ± 3.55 cm^3 and 9.62 ± 3.21 cm^3, respectively. Also, the main FS volumes were, in hand mode and semi-automatic mode, 5.32 ± 2.04 cm^3 and 6.65 ± 2.70 cm^3, respectively.
We identified only one article in the literature that calculates the area of the FS and SS. The calculations in a study by Kapakin[17] showed the FS area to be 6.03cm^2 on the right and 5.79 cm^2 on the left, and 1.48 cm^2 and 2.82 cm^2 for the right and left areas of the SS, respectively. In our study, the main FS areas were, in manual mode and semi-automatic mode, 3.88 ± 1.60 cm^2 and 3.91 ± 1.58 cm^2, respectively. Also, the main SS areas were, in hand mode and semi-automatic mode, 4.80 ± 1.86 cm^2 and 4.84 ± 1.83 cm^2, respectively. Different methods were considered to be the reason for the different results in both studies. Kapakin[17] first created photorealistic models of the paranasal sinuses designed with CAD-CAM support and then calculated the area measurements with 3D software. In our study, all measurements were calculated directly with the 3D software on the CT images of the patient. Since few articles in the literature compare the segmentation modules of programs, the data obtained from our study - similarly Szabo et al.[21]- were compared with existing data in the literature. As a result of this study, it was apparent that the values measured in both semi-automatic segmentation and manual segmentation are close to those presented in the mean literature data (Tables 1 and 2). That the values of the semi-automatic segmentation are higher than the manual segmentation measurement may be the result of including in this module every occurrence within the sinus boundaries of the program. In manual segmentation, only the area and volume covered by the air in the sinus are measured due to the thresholding value entered to mark the airway. However, in semi-automatic segmentation is included in the measurement of area and volume in structures such as septa and polyp in the sinus.
One of the differences between the two modules is measurement time. While the boundaries of the anatomical structure to be measured in semi-automatic segmentation are determined in several sections, the structure is ready for measurement; in manual segmentation, however, the boundaries of the anatomical structure must be determined in each section. Therefore, semi-automatic segmentation is one step ahead in measurement speed.
This study has some limitations worth noting. First, the true volumes of the anatomical structures whose volume and area were measured are unknown. It is thought that comparing the actual volumes of the sinuses of each patient will give more accurate results. Another limitation is that different programs produce different volume and area measurements results.

Conclusion

Apart from the evaluation of the intended anatomical structures, we think that observations to determine whether the software modules include similar structures in this structure will be more reliable in creating artificial maxillofacial structures.

Acknowledgements

No.

Conflict of Interest

The authors declare no conflicts of interest.

Financial Support

The authors declare no financial support

Compliance of Ethical Statement

This study was approved by the Local Ethics Committee of Hatay Mustafa Kemal University (Decision no: 20)

Author Contributions

CAB: Study conception and design; CAB, GS: Data Collection, literature search, resources, statistical analysis, CAB: Manuscript drafting/writing; GS: Manuscript Editing

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