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Calculation Of The Total Volume Of The Maxillary Sinuses Using CBCT Images And ITK-SNAP Software.

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Abstract
Purpose: The objective of this study is the analysis of the reliability of the ITK-SNAP software in calculating the total volume of the maxillary sinuses, as well as their visualization in 3D.
Materials and Methods: A total of 68 patients were included in this study, 26 men and 42 women, with an age between 40 and 76 years. A total of 129 maxillary sinuses were studied.
Results: In the right maxillary sinus, the minimum value was 2648 mm³, the maximum value was 29650 mm³, and the mean was 13978 mm³. In the left maxillary sinus, the minimum value was 3246 mm³, the maximum value was 27200 mm³, and the mean was 14950 mm³.
Conclusion: The ITK-SNAP software is a useful tool in calculating the total volume of the maxillary sinus, due to its effectiveness in measurements, its speed and simplicity, as well as the 3D image it provides.
Keywords: Maxillary sinus; ITK-SNAP; Volume of maxillary sinus; CBCT; Volumetric analysis.

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I. Introduction

One of the methods that currently exist to calculate the volume of the maxillary sinuses consists of taking measurements on images obtained by Computed Axial Tomography (CT) or by Cone Beam Computed Tomography (CBCT). Studies published in this regard, was the one carried out by Ariji et al.[1] in 1994, in which they measured the normal volume of the maxillary sinus by means of axial CT in 115 cases, and analyzed the relationship with age, presence of premolars and molars, size of the facial skeleton, and height and width of the body. In 1996, Ariji et al.[2] published a study that aimed to determine the normal range of maxillary sinus size and its changes with age using computed tomography (CT).

In 1998, Uchida et al.[3] published a study that aimed to measure maxillary sinus size in 32 cadavers, or a total of 59 sinuses, to be used as an aid to determine bone graft volume before surgery. These authors published a similar work in the same year, in which they studied a total of 38 sinuses using CT and 3D reconstruction[4].

Other studies published on the calculation of the volume of the maxillary sinuses using images obtained by CT scan are the published in 2010 by Shahbazian et al.[5] who analyzed the anatomy of the maxillary sinus, its variations and volume using spiral computer tomography scans. Kirmeier et al.[6] in 2011, tested a semi-automatic virtual volumetric analysis technique on 36 computed tomography scans of human maxillary sinuses. They state that this computed tomography measurement procedure could be strongly recommended for clinical applications to reliably determine human maxillary sinus volume. In that same year, Deeb et al.[7] used images obtained by CT scan to study sinus volume in patients with chronic rhinosinusitis.

Other authors used this type of images with different purposes, such as the prevalence, location, size and course of the anastomosis between the dental branch of the posterior superior alveolar artery (PSAA), known as alveolar antral artery (AAA), and the infraorbital artery (IOA)[8,9] or the sex determination by morphometric analysis of the maxillary sinus[10].

Recently, the use of images obtained by CT scan for the study of the maxillary sinus has been replaced by images obtained by Cone Beam Computed Tomography. We can find in the literature several articles that use this type of CBCT images for the study of different aspects of the maxillary sinus, such as the analysis of possible anatomical variations[11], their pneumatization[12,13], as well as the effect that the patient's age and sex may have on sinus volume[14], the 3D-evaluation of the maxillary sinus[15], and the individual's sexual determination through volumetric analysis of the maxillary sinuses[16,17,18].

The purpose of this study is to analyze the reliability of the ITK-SNAP software as a tool to calculate the total volume of the maxillary sinuses, as well as to visualize them in 3D. We consider that it can be useful both from a clinical point of view, since it helps us in the diagnosis and in the planning of a treatment, as from the anatomical point of view, since it allows us a greater knowledge of the maxillary sinuses.

II. Material and methods

The images obtained by performing cone beam computed tomography (CBCT) that we used in this study belong to the data file of the Radiology Unit of the Faculty of Dentistry of the University of Santiago de Compostela, which were performed for diagnostic purposes, prior signature by the patients of the timely informed consent.

All patient data was processed in accordance with the provisions of Organic Law 3/2018 on the Protection of Personal Data and guarantee of digital rights. The data were taken between 27 January 2019 and 14 February 2020.

This study was examined by the Bioethics Committee of the University of Santiago de Compostela, ruling that the experimental protocol meets the ethical requirements. This study has been carried out according to the STROBE guidelines.

Selection of patients.

A total of 68 patients were included, 26 men and 42 women, with an age between 40 and 76 years. A total of 129 maxillary sinuses were studied. To select the images that were included in this study, we defined the following inclusion and exclusion criteria:

-Inclusion criteria

-Patients who present partially or totally edentulous posterior sectors at the level of the maxilla, and may be unilateral or bilateral.

-These patients who gave their consent for their diagnostic images to be used in research work were part of this study.

-Exclusion criteria:

-Patients with cystic or tumor pathology in this region.

-Patients who have undergone any surgical intervention in the area, including the presence of dental implants at this level.

-Patients with large defects, malformations and / or large asymmetries in these regions.

Radiographic study.

CBCTs were taken using the i-CAT device (Imaging Sciences, Hatfield, PA, USA), with exposure parameters of 120 kVp and 5 mA, acquisition time of 14.7 s and variable reconstruction, with voxel size of 0.25 mm and FOV (Field of View) of 16 cm (diameter) x variable height (4 to 7 cm).

Anonymization of data.

Once we selected the CBCT that met the requirements for our study, and in accordance with the current regulations of the data protection law, we proceeded to anonymize the personal data that may appear reflected in it. For this we used DicomCleaner TM software, which is a free open source tool with a user interface for importing, cleaning and saving DICOM files.

Carrying out measurements.

To carry out the measurements, we used the ITK-SNAP program, which is a software application used to segment structures in 3D medical images. It is the product of a decade of collaboration between Paul Yushkevich, Ph.D., of the Penn Image Computing and Science Laboratory (PICSL) at the University of Pennsylvania, and Guido Gerig, Ph.D., from the Scientific Computing and Imaging Institute (SCI) at the University of Utah. ITK-SNAP is free, open source, and cross-platform. Provides semi-automatic segmentation using active contour methods, as well as manual delineation and image navigation[19].

This software allows visualization in different planes (axial, coronal and sagittal) and image manipulation, optimized by three-dimensional reconstructions. In our study, we used the ITK-SNAP 3.6.0 version, referred to on its website as the “stable version”.To download it, we simply follow the instructions they show us on their website.

In order to start working with a CBCT, we will go to the “open main image” section selecting the desired case. Once we import the image in DICOM format, we select the image we want to work with. When the image is open, we proceed to select the sections in which the anatomical area to be studied is correctly appreciated, in this case we are showing the right maxillary sinus as an example. We then use the “Snake ROI tool”, which is used to select the region of interest for the semi-automatic active contour segmentation, and start the semi-automatic segmentation wizard. In this case, its limits were the walls of the right maxillary sinus (anterior, posterior, lateral, medial, superior and inferior) (Fig. 1a).

A square will appear that we must adapt to the anatomical area that we want to segment.

Next, we go to the “Segmentation” box, and among the options that it shows us, we will select the “Label Editor” section. Once the labeling has been carried out correctly, we will go to the "Segment 3D" key to start the semi-automatic segmentation process.

The images corresponding to the anatomical areas that are within the previously established limits will appea.

We will then proceed to adjust the upper and lower threshold values as well as the smoothness. In this case, we work with a lower threshold limit with values around -1000, and a threshold limit higher with values around -600.

Likewise, the value for the smoothness parameter was 3 (Fig. 1b).

In any case, we must adjust these values individually each time we perform a segmentation, until we achieve a precise image of what we want to isolate. When we are satisfied with the image achieved, we will go to the "Next" key.

At this moment, we will begin to add bubbles in the selected spaces of the images to be segmented, being able to select their size, until they are filled. In the next step we will select the “Size speed” and press the “Play” key to start the process, allowing us to view it.

When we see that the segmentation is correctly carried out, we will finish it by pressing the “Finish” key. The segmentation of the selected image will appear on the screen, in this case the maxillary sinus, in the axial, sagittal and coronal slices. At this moment, we will press the “Update” key, and the three-dimensional image of the segmented area will be loaded in the lower left window of the screen (Fig. 1c).

Next, we will repeat the process for the left maxillary sinus.

Once the process is done, we will obtain the images corresponding to the two segmented maxillary sinuses

This software allows the three-dimensional visualization of both maxillary sinuses on the same screen, as well as the possibility of moving them in the different planes of space (Fig. 1d).

Fig 1.

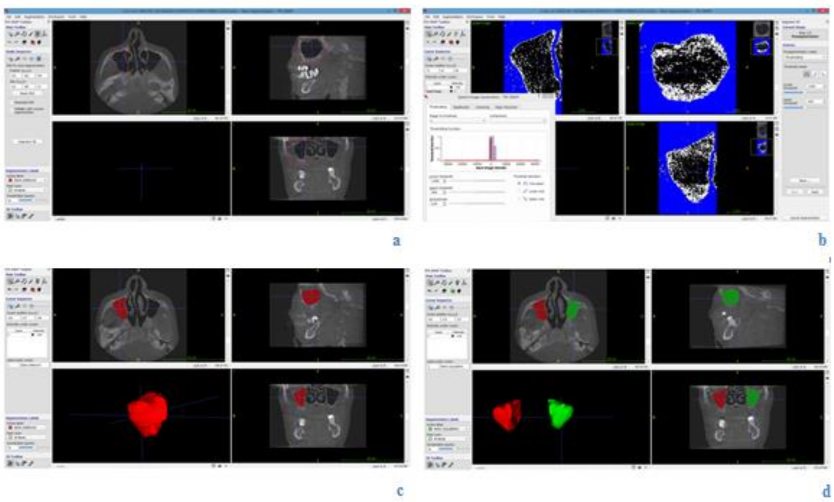
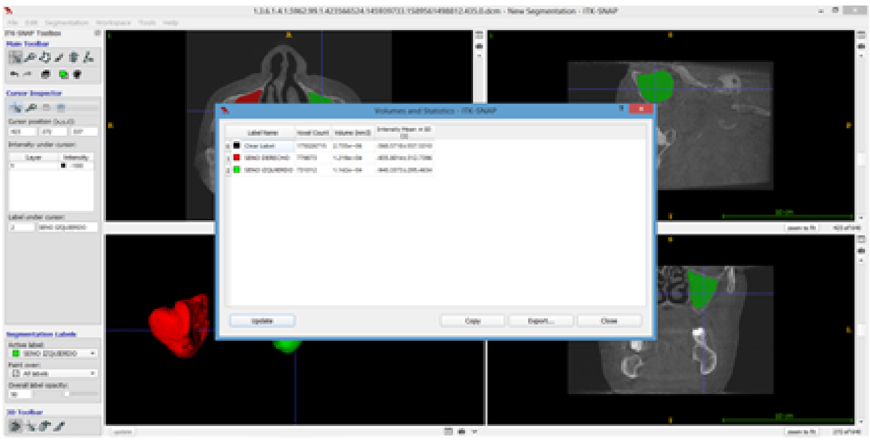


Image of selected area of interest (a). Image of the selected parameters (b). 3D image of the right maxillary sinus (c). Image corresponding to the two maxillary sinuses (d).

Then we go to the section "Volume and Statistics" and we will obtain the volume of both maxillary sinuses in cubic millimeters. Finally, we will save the segmented image and the workspace by assigning it a specific name (Fig. 2).

Fig 2.



Total volume of maxillary sinuses in mm³.

III. RESULTS

A total of 68 patients were included in this study, 26 men and 42 women, aged between 40 and 76 years. A total of 129 maxillary sinuses were studied. Statistical treatment of the data was performed using software R (www.r-project.org, version 4.1.0)[20].

Total volume right and left maxillary sinuses

The results obtained in the present study are shown in Table 1.

Table 1.

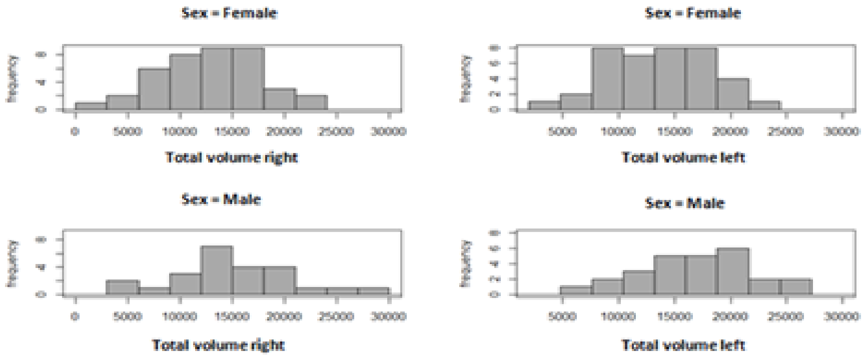
		Total Data	Female	Male
Number of missing teeth right side	min	0	1	0
	max	5	5	5
	mean	3.453	3.70	3.041
Number of missing teeth left side	min	0	0	0
	max	5	5	5
	mean	3.5	3.666	3.240
Total volume right maxillary sinus (mm³)	min	2648	2648	4217
	max	29650	21870	29650
	mean	13978	13108.08	15427.42
Total volume left maxillary sinus (mm³)	min	3246	3246	6020
	max	27200	21630	27200
	mean	14950	13608.38	16961.35

This table shows the total values obtained from the parameters analyzed and the values obtained in each sex.

Total volume and sex relationship

When we evaluate these variables using the Wilcoxon Mann-Whitney test we observe that on the right side there are no statistically significant differences ($p = 0.106$). However, on the left side we could see that there are statistically significant differences ($p = 0.009$). The value of the mean on the left side is higher in male (16961.35) than in female (13608.38) (Fig. 3).

Fig 3.

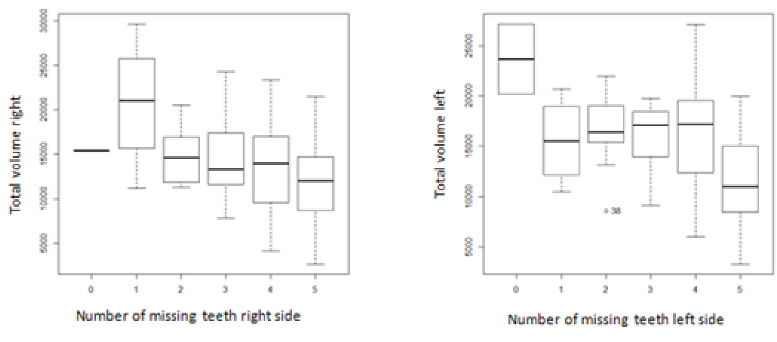


Maxillary sinuses volumes obtained in male and female.

Relationship between total volume and number of missing teeth

To see the possible relationship between the variables total volume and the number of missing teeth, we used the Kruskal-Wallis test, not obtaining statistically significant results on the right side ($p = 0.302$), but on the left side ($p = 0.011$) (Fig. 4).

Fig 4.

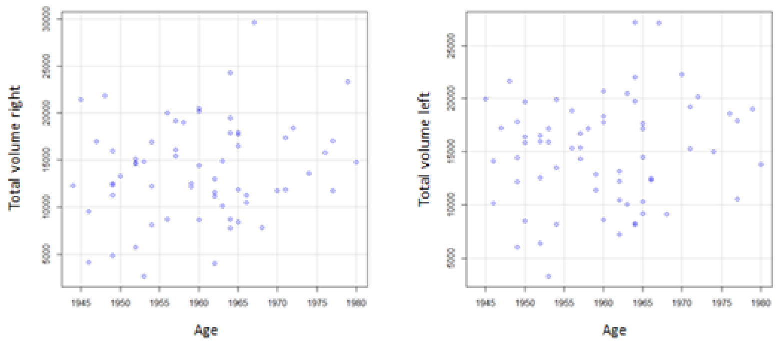


Distribution of the volumes obtained in relation to the number of missing teeth.

Relationship between total volume and age

To see the possible relationship between the variables total volume and age, we used the Spearman correlation coefficient, not observing statistically significant differences on the right side (*p = 0.352*), nor on the left (*p = 0.390*) (Fig. 5).

Fig 5.



Distribution of the volumes obtained according to age.

IV. Discussion

The values of the total volume that we have obtained in the present study are comparable to those published in 2018 by Luz et al.[15] for the total volume of the bony sinus, being 28.9 cm³ as the maximum value, 4.0 cm³ as the minimum value and an average value of 17.1 cm³. A total of 128 maxillary sinuses were analyzed in 64 patients using data cone beam computed tomography scan. To calculate the volume they used the implant planning software SMOP (Swissmeda AG, Baar, Switzerland).

Our results differ from those obtained by Gulec et al.[14], who describe a mean volume of the right maxillary sinus was 13,173 cm3, while for the left was 13,194 cm3. This may be due to the sample selected by these authors, with an age range ranging from 8 to 51 years.

With reference to the differences in volume between the different sides, we observed similar results, agreeing with other authors (Ariji et al.[1], Luz et al.[15], Uchida et al.[3,4]).

Regarding the difference in volume between sexes, on the right side we did not observe statistically significant differences (*p = 0.106*), but we did observe on the left side (*p = 0.009*), being greater for male. This result coincides with that obtained by Luz et al.[15], who observed that both maxillary sinuses (bone margins) of each patient were quite similar in size (mean difference between the left and right 0.5 cm3), but statistically significant with slightly smaller volumes higher on the left side (*p = 0.045*). Male were found to have statistically significant higher mean bone volume (19.0 cm3) than female (15.5 cm3). These data also coincide with those obtained by other authors such as Möhlhenrich et al.[10], Velasco-Torres et al.[21]). Farias Gomes et al.[18], performed linear and volumetric measurements of the maxillary sinuses for sex determination in forensic sciences. Used the ITK-Snap software, obtaining results that suggest that the volume of the maxillary sinus is greater in male. However, these results differ from those provided by Gulec et al.[14] who did not observe that gender had an influence on sinus volume.

With regard to the relationship between the total volume and tooth absences, we have obtained statistically significant differences on the left side, (*p =0.011*), appreciating a greater sinus volume in those cases with fewer missing teeth. These results partially coincide with those described by Velasco-Torres et al.[21] who observed that the total volume of the maxillary sinus was significantly lower in the totally and partially edentulous patients than in the dentate ones. However, other authors such as Schriber et al.[13] consider that edentulism has no impact on the dimensions of the sinuses, suggesting that there is no continuous pneumatization in the maxillary sinus after tooth loss. They state that after tooth loss in the posterior maxillary region, the loss of vertical bone height is primarily due to resorption of the alveolar ridge, and not to pneumatization of the maxillary sinus. Shahbazian et al.[5] did not find statistically significant differences in the dimensions of the maxillary sinus for mainly dentate and edentulous patients, as did Luz et al.[15] who did not appreciate a significant association between dentition status and sinus volume.

Relating to the relationship between age and total volume, we did not find significant differences in our study. These results coincide with those obtained by different authors, such as Gulec et al.[14], Luz et al.[15], Schriber et al.[13], Uchida et al.[3,4]. However, they differ from those obtained by Velasco-Torres et al.[21], who in a study published in 2017, observed that older patients showed lower volume, regardless of sex and edentulous status.

V. Conclusion

The present study shows that the ITK-SNAP software is a useful tool to calculate the volume of the maxillary sinuses, since in addition to providing it in mm³, it allows us to visualize it in 3D.

Authors contibution

C-M, D. and P-G, N. designed the study. C-M, D. performed the radiological analysis. C-M, D. and P-G, N. were responsible for the preparation of the manuscript. M-S, I.M. performed the statistical analysis. S, J.M. directed and supervised the study. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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