

Comparison between Manual and Semi-automatic Segmentation of Nasal Cavity and Paranasal Sinuses from CT Images

K. Tingelhoff, A. I. Moral, M. E. Kunkel, M. Rilk, I. Wagner, K. W. G. Eichhorn,
F. M. Wahl, F. Bootz

Abstract— Segmentation of medical image data is getting more and more important over the last years. The results are used for diagnosis, surgical planning or workspace definition of robot-assisted systems. The purpose of this paper is to find out whether manual or semi-automatic segmentation is adequate for ENT surgical workflow or whether fully automatic segmentation of paranasal sinuses and nasal cavity is needed. We present a comparison of manual and semi-automatic segmentation of paranasal sinuses and the nasal cavity. Manual segmentation is performed by custom software whereas semi-automatic segmentation is realized by a commercial product (*Amira*). For this study we used a CT dataset of the paranasal sinuses which consists of 98 transversal slices, each 1.0 mm thick, with a resolution of 512 x 512 pixels. For the analysis of both segmentation procedures we used volume, extension (width, length and height), segmentation time and 3D-reconstruction. The segmentation time was reduced from 960 minutes with manual to 215 minutes with semi-automatic segmentation. We found highest variances segmenting nasal cavity. For the paranasal sinuses manual and semi-automatic volume differences are not significant. Dependent on the segmentation accuracy both approaches deliver useful results and could be used for e.g. robot-assisted systems. Nevertheless both procedures are not useful for everyday surgical workflow, because they take too much time. Fully automatic and reproducible segmentation algorithms are needed for segmentation of paranasal sinuses and nasal cavity.

I. INTRODUCTION

THE morphological knowledge of nasal cavity and paranasal sinuses has an important clinical value. It is used for the detection of sinus pathologies, for determination of therapy, planning of endonasal surgeries and for surgical simulations. Current research and industry developments for ENT surgery generate robot-assisted systems [1, 2] or navigated control [3]. These assisting systems need a workspace definition of the paranasal sinuses,

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K. Tingelhoff, I. Wagner, K.W.G. Eichhorn and F. Bootz are with the Clinic and Polyclinic of Otolaryngology/Ear, Nose and Throat Surgery, University of Bonn, Germany (phone: 0049-228-2871-5552; e-mail: kathrin.tingelhoff@ukb.uni-bonn.de)

M.E. Kunkel, A.I. Moral, M. Rilk and F.M. Wahl are with Institute of Robotics and Process Control, Technical University Braunschweig, Germany (phone: 0049-531-391-7450; e-mail: eku@rob.cs.tu-bs.de)

which is realized by segmentation.

The most simplest and important index employed in the evaluation of the paranasal sinus is the volume quantification [4]. For endoscopic sinus surgery, it is essential that the surgeon has exact knowledge of the anatomy and anatomic variations of nasal cavity and paranasal sinuses. Anatomical variations of paranasal sinuses can be distinct for different patients, as it can be seen by the number of ethmoidal cells, ranging from 3 to 18 per side [5, 6].

To obtain a 3D-representation, the images should be segmented and a volume will be reconstructed. One limitation of using CT imaging routinely for reconstruction of the nasal cavity and paranasal sinuses is the time consumption for manual segmentation. To process the CT images faster, several semi-automatic [7, 8] and automatic segmentation routines [9, 10] have been developed. For paranasal sinuses no automatic segmentation approaches exist so far, which is caused by the complex anatomy and high anatomical variability.

In this paper, a comparison between manual and semi-automatic segmentation of nasal cavity and paranasal sinuses from CT images is presented.

II. MATERIALS AND METHODS

For this study we used a CT dataset that was generated by a spiral CT from Philips. The dataset of the paranasal sinuses consists of 98 transversal slices, each 1.0 mm thick, with a resolution of 512 x 512 pixels. The pixel spacing is 0.346 mm x 0.346 mm. The dataset is acquired from a female patient age 37. It shows little chronic maxillary sinusitis (bilateral) and bullose middle turbinate (bilateral). Furthermore the patient has unaffected paranasal sinuses.

In order to get comparable results, some general instructions were provided for manual and semi-automatic segmentation. We outlined all paranasal sinuses (left and right side) including nasal cavity. The first and last coronal slice was assigned for both procedures. Sphenoidal and frontal sinuses were segmented separately. Each paranasal sinus and the nasal cavities were outlined following its inner mucosa surface, i.e. the mucosa is considered to be inside the segmented region.

In earlier experiments we compared the results of manual segmentation based on different Hounsfield windows: complete Hounsfield window, bone window, mucosa window and a user defined window. The results show little standard deviation for all volumes which is 2.6 % of the mean volume. During another experiment we computed the

intraoperator variability of manual segmentation based on CT image data. The results show 3 % standard deviation of the mean volume. The variances in both procedures are similar. There seems to be no advantage to work with certain Hounsfield windows. So we decided to work on the complete Hounsfield range for both segmentation procedures. Manual and semi-automatic segmentation was performed by two experienced participants concerning CT image data, the paranasal anatomy and the segmentation tool they used.

To compare manual and semi-automatic segmentation results we propose four indices: a) volume, b) extension (length, height and width), c) segmentation time and d) visual analysis.

A. Experimental Setup I: Manual Segmentation

In this case the custom software can load and display DICOM datasets in coronal, transversal and sagittal views. The user can click through the dataset slice by slice for each view. The software provides line segmentation. The user marks several points and the software draws straight lines between the two points.

After segmentation the data needs to be postprocessed by several steps. First the contour is closed, and afterwards the sinuses are filled separately. Figure 1a shows the manual segmentation result after post processing.

For the volume computation, the number of voxels belonging to each sinus is counted and the result is multiplied by the volume of one voxel in cm^3 . The extension in x-, y- and z-direction is measured parallel to the object coordinate system of the CT dataset. For each sinus the software automatically determines the first and last voxel in each coordinate direction. For the extension in z-direction the first and last voxel in that direction is determined and the distance of the z-coordinate is computed.

3D-reconstruction is generated after the segmentation results are postprocessed. We used a Gaussian filter five times consecutively in order to smooth the binary segmentation results. Afterwards marching cubes is used for generating the 3D-mesh.

B. Experimental Setup II: Semi-automatic Segmentation

Semi-automatic segmentation is performed using Amira 4.1 segmentation software for medical images (Mercury Computer System, Inc., USA). The software uses 3D growing region. Starting from a manual chosen seed point the largest connected region is segmented with voxels whose gray values lie inside a user defined range. The postprocessing is performed slice by slice. It is possible to segment all sinuses by these two steps [11].

For the nasal cavity, due to the anatomical complexity, the segmentation has to be performed slice by slice. Figure 1b describes the semi-automatic segmentation process of the nasal cavity and the paranasal sinuses. After segmentation a triangular approximation of the interfaces between air and nasal cavity mucosa is computed.

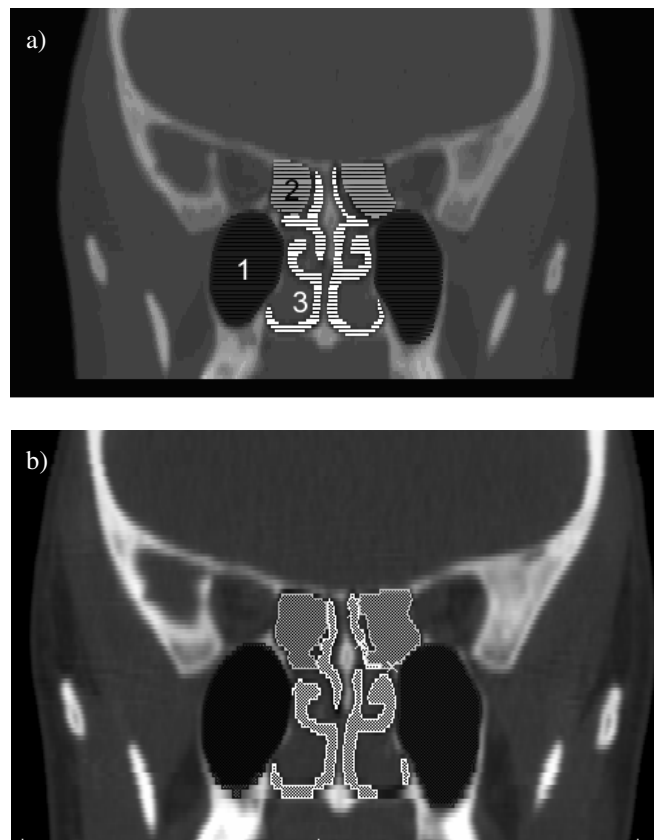


Fig 1. Segmentation results in a 2D-slice. Postprocessed sinuses of a) manual segmentation and b) semi-automatic segmentation; maxillary sinus (1); ethmoidal sinuses (2); nasal cavity (3).

This process can take up to one minute. An unconstrained smoothing is used. This generates sub-voxel weights, so that the surface is naturally smooth. For the measurements of the height, width and length, landmarks are used. They are put in the first and last segmented point of a sinus for each coordinate direction. Afterwards we compute the distance of the first and last point parallel to the coordinate system.

III. RESULTS

A. Time involved in each Segmentation Procedures

We have recorded the time to place the contours on all images manually and semi-automatically. The percentages of the total time devoted to segmentation, correction, to compute volume and distances and for 3D-visualization were calculated and are reported in Table I. The interaction time was reduced from 980 minutes of manual segmentation to 215 minutes for semi-automatic segmentation. The total time for manual segmentation was compared with the total and interaction times for semi-automatic segmentation.

TABLE I
SEGMENTATION TIME FOR EACH PROCEDURE

Procedure	Time (min)
Manual segmentation	
Step 1: segmentation	600
Step 2: correction	300
Step 3: compute volumes and distances	60
Step 4: 3D-visualization (computation time of the algorithm)	20
Total*	980
Semi-automatic segmentation	
Step 1: segmentation	120
Step 2: correction	30
Step 3: compute volumes and distances	60
Step 4: 3D-visualization (computation time of the algorithm)	5
Total*	215

Note: *Steps 1,2, 3 and 4

B. Volumes and 3D-Extensions of the Paranasal Sinuses and the Nasal Cavity

The paranasal sinuses and nasal cavity volumes and extensions that were estimated using manual and semi-automatic segmentation methods are summarized in Table II and III.

TABLE II
VOLUMES OF THE PARANASAL SINUSES AND THE NASAL CAVITY

Paranasal sinuses	Estimated Volume (cm ³)	
	Manual segmentation	Semi-automatic segmentation
Maxillary	Right	20.1735
	Left	20.7053
Sphenoid	Right	8.6717
	Left	2.7351
Ethmoid	Right	5.1785
	Left	6.4511
Frontal	Right	8.1394
	Left	6.8422
Nasal Cavity	22.7292	24.2401

Note: length- antero-posterior; height-cranio-caudal; width - transverse.

TABLE III
3D-EXTENSIONS OF THE PARANASAL SINUSES

Paranasal sinuses	Estimated 3D-measurements (mm)						
		Manual segmentation			Semi-automatic segmentation		
		Length	Height	Width	Length	Height	Width
Maxillary	R	46.0	42.0	31.5	45.6	44.6	36.9
	L	45.3	44.0	32.8	45.6	44.6	34.2
Sphenoid	R	35.6	29.0	34.6	43.3	32.4	37.1
	L	25.2	20.0	14.9	27.3	24.3	18.3
Ethmoid	R	41.5	30.0	15.6	42.0	36.9	15.7
	L	45.3	32.0	18.3	45.6	37.4	19.8
Frontal	R	21.8	39.0	41.8	25.8	40.3	45.5
	L	28.0	46.0	32.8	29.0	46.0	33.0

Note: R (right) L (left)
Length: antero-posterior; height: cranio-caudal; width: transverse.

C. 3D-Reconstruction of the Nasal Cavity and the Paranasal Sinuses

Figure 2 shows the 3D-reconstructions from manual (a, b) and from semi-automatic segmentation (c, d) of the nasal cavity and paranasal sinuses from CT images.

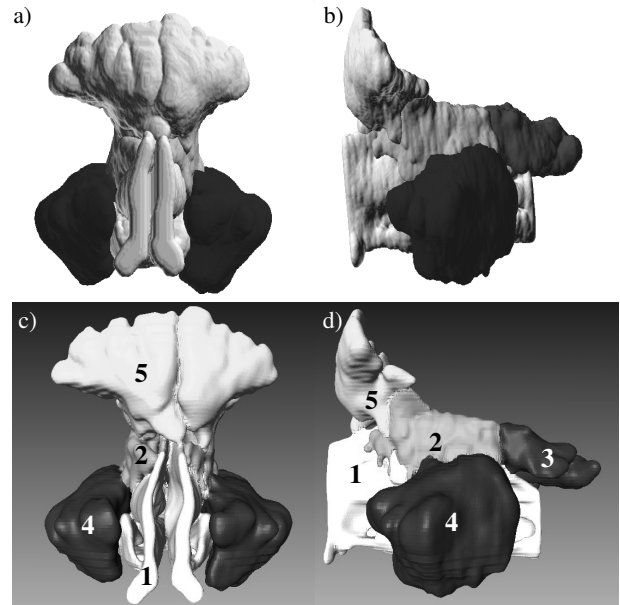


Fig 2. 3D-reconstruction of the nasal cavity and paranasal sinuses from CT images: Nasal cavity (1); Ethmoidal sinus (2); Sphenoidal sinus (3); Maxillary sinus (4); Frontal sinus (5). Frontal (a) and lateral (b) reconstruction from manual segmentation and frontal (c) and lateral (d) reconstruction from semi-automatic segmentation.

IV. DISCUSSIONS

Current results of research and industrial developments [1, 2, 3] demonstrate that segmentation of paranasal sinuses are of great interest for surgical ENT workflow.

The need of paranasal sinus segmentation and the time consuming segmentation make automation necessary. Is semi-automatic segmentation adequate for ENT surgical workflow or do we need fully automatic segmentation algorithms?

The volumes of manual and semi-automatic segmentation deliver similar results (Table II). Maximal variance appears for nasal cavity which shows a difference of 6.2 %. The difference can be caused by the complex and narrow anatomy, swollen mucosa and secretion which makes it difficult to find the borders. Table III shows consistently smaller volumes for manual segmentation even though the results for all sinuses show only little variances. Statistical differences between the volumes of the paranasal sinuses obtained with both processes were not significant, and in the values range reported from others studies [4, 12].

In earlier experiments we determined the degree of the inter- and intraoperator variability [13]. The segmentation procedure was realized by two participants so the differences of the segmentation results include interoperator variability. Depending on the volume and the accuracy there seem to be no advantage of either procedures. In other studie, a 3D-mesh of a dummy human head without the paranasal sinuses volume was created, using Amira software, for surgery simulations [14].

In the present study, the differences of the measured extensions can be caused by different acquisition techniques

(Table III). The custom software automatically determines the first and last voxel in each of the three coordinate directions. Amira does not provide this feature, so the participant has to mark landmarks. These landmarks are subjective and can deliver imprecise results.

3D-reconstruction of manual segmentation software and Amira delivers similar results (Fig. 2). Robot assisted surgery systems for paranasal sinus surgery [1, 2] need a workspace definition in which the robot may move e.g. the endoscope. The definition of the configuration space will be based on the 3D-volume of our reconstruction.

As our experiments show, manual segmentation takes 980 minutes for outlining paranasal sinuses and nasal cavity. This is not practical for everyday surgical workflow. In the literature we did not find any other anatomical structure which needs as much time for manual segmentation [15, 16]. The reason is based on the complex anatomy of paranasal sinuses with their thin bony structures (ethmoidal sinuses) that can hardly be seen in CT datasets. Our experiments show that semi-automatic segmentation using Amira saves time up to 765 minutes which is a reduction of 78.1 %. Literature shows similar improvements between manual and semi-automatic segmentation. Duan et al. [16] segmented endocardial and epicardial boundaries of the myocardium based on cine-MRI (magnet resonance imaging) images. He presents a reduction of 83.3 % – 91.7 % between manual and semi-automatic segmentation. Hermoye et al. [15] segmented the liver based on MRIs. Segmentation time was reduced up to 80 %.

Nevertheless semi-automatic segmentation of paranasal sinuses takes 3.5 hours, which is still not practical for everyday workflow.

V. CONCLUSION

In our experiment we compared manual (custom software) and semi-automatic segmentation (*Amira*) of paranasal sinuses and nasal cavity. We wanted to find out whether manual or semi-automatic segmentation is adequate for ENT surgical workflow. The results were assessed by four indices: volume, extension, time and visual analysis.

For both segmentation procedures we delivered similar volumes, extensions and 3D-reconstructions. Depending on the segmentation accuracy both methods, manual and semiautomatic segmentation can be used for clinical applications.

Main difference is the time being concerned. Semi-automatic segmentation takes 3.5 hours for detailed segmentation of paranasal sinuses and nasal cavity which is still not practicable. Therefore fully automatic algorithms for segmentation of paranasal sinuses and nasal cavity are needed. Depending on the complex anatomy we think that only model-based approaches can solve this task.

In our future work we are going to compare these two methods not only with other segmentation techniques but also with experimental measurements of the paranasal sinuses volumes from cadavers.

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