Automated 3D Segmentation of the Esophagus For Planning of Atrial Ablation Therapy

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Introduction

Atrial fibrillation is the most common cardiac arrhythmia and can be treated with catheter ablation inside the left atrium of the heart known as atrial ablation therapy. During this intervention the esophagus, which has contact with the left atrium, can be thermally injured by the heat at the tip of the catheter and air can enter via the esophagus into the left atrium. There have been several reported cases of death resulting from this complication [1]. Therefore the ablative power should be reduced at the atrial-esophageal contact area.

A segmentation of the esophagus is useful to visualize the contact area, however it is difficult to segment the esophagus in CT images with standard edge-based techniques because it is surrounded by tissue of similar density. A model-based esophagus segmentation approach by Rousson et *al*. [2] yields good results but is time-consuming and requires a previous segmentation of the aorta and two points on the esophageal centerline.

In this work we propose a novel, fully automated segmentation technique for CT images that detects axial esophageal contours around intraesophageal air holes and interpolates them to generate a 3D segmentation.

Materials and Methods

Our esophagus segmentation algorithm consists of 8 main steps which are illustrated in Fig. 1.

The first step extracts a subvolume (volume of interest, VOI) of the entire cardiac CT data set that is located relative to the segmented left atrium. The second step uses the threshold value I_{air}=-400 Hounsfield units (HU) to classify voxels with intensities lower than I_{air} as air. The third step classifies air inside the respiratory organs (lungs, bronchi, trachea) by applying a volume growing algorithm [3] with seed points at air voxels at the left and right boundary of the VOI. The binary volumes of step 3 and 2 are subtracted (fourth step). The resulting volume stores the air in the VOI that is not connected to the boundaries of the VOI. This is the esophageal air, because air inside the VOI can either exist in the respiratory organs or inside the esophagus.

Single esophageal air holes are determined in the fifth step by identifying connected components of esophageal air. Beam hardening artifacts [4] have low HU values and are located very close to highly contrasted structures (e.g. contrast agent). They can be misclassified as air and are detected in the sixth step that evaluated the intensity histogram around each potential air hole. If very high intensity values are present close to the air hole than it is rejected. The seventh step determines the axial esophageal contour around the air hole by dilatation using a spherical structuring element with a radius of 3 mm which is an empirical value.

Two esophageal contours, at the cranial and at the caudal side of the left atrium, are finally used in step 8 to generate a 3D structure of the esophagus. The 3D segmentation is obtained by interpolating the Fourier descriptors [3] of the contours and inverse transforming the interpolated descriptors back into the spatial domain. As a side constraint, the result must not intersect with the convex-shaped left atrial wall. If, in one axial slice, an intersection of the two organs occurs the esophagus is moved into the opposite direction of the summed vectors from the center of the contour to the intersecting points, i.e. away from the left atrium.

Validation

A measure for the accuracy of the 3D esophagus segmentation is the mean distance d_{center} of the esophageal centerline between a segmentation result and a manually drawn ground truth. 12 pre-interventional cardiac CT scans (Somatom® Sensation 16, Siemens Healthcare) of patients treated with atrial ablation therapy were used to validate the segmentation technique. The voxel volumes were approximately $(0.35 \cdot 0.35 \cdot 0.6)$ mm^3.

Esophageal air holes were found in all data sets. Visual inspection showed that some small air holes with intensities greater than I_{air} were missed. One air hole was misclassified. The average number of detected air holes was 4.7 ± 2.6 and the computational time of the entire algorithm was about 5 seconds on a standard PC. In 4 data sets air holes were detected at the cranial *and* caudal side of the left atrium. The segmentation accuracy in these 4 data sets was $d_{center} = (3.28 \pm 1.18)$ mm. Two segmentation results are shown in Fig. 2 and visualizations of the boundary of the atrial-esophageal contact area are shown in Fig. 3.

Discussion

For a fully automated segmentation air holes need to be detected at the cranial *and* caudal side of the left atrium. However, because of physiological reasons, the number of intraesophageal air holes varies widely among individuals and only in one third of the data sets used for validation they were detected on both sides. Intraesophageal air holes are essential to determine esophageal contours. If contours cannot be determined automatically the user could draw contours manually making the segmentation technique semi-automatic. The accuracy of the segmentation is sufficient to determine the gross esophageal route at the left atrium.

Conclusion and Outlook

A fast and fully automated 3D segmentation of the esophagus in CT images is possible using the presented method and accurate results for planning of atrial ablation therapy are achieved.

An interesting field of research would be the increase of the amount of intraesophageal air and thus the air holes detection rate. It could be achieved by asking the patient to swallow air shortly ahead of the imaging. This procedure would be more favorable than, e.g., the oral administration of a barium cream contrast agent which is an existing procedure in clinical practice.

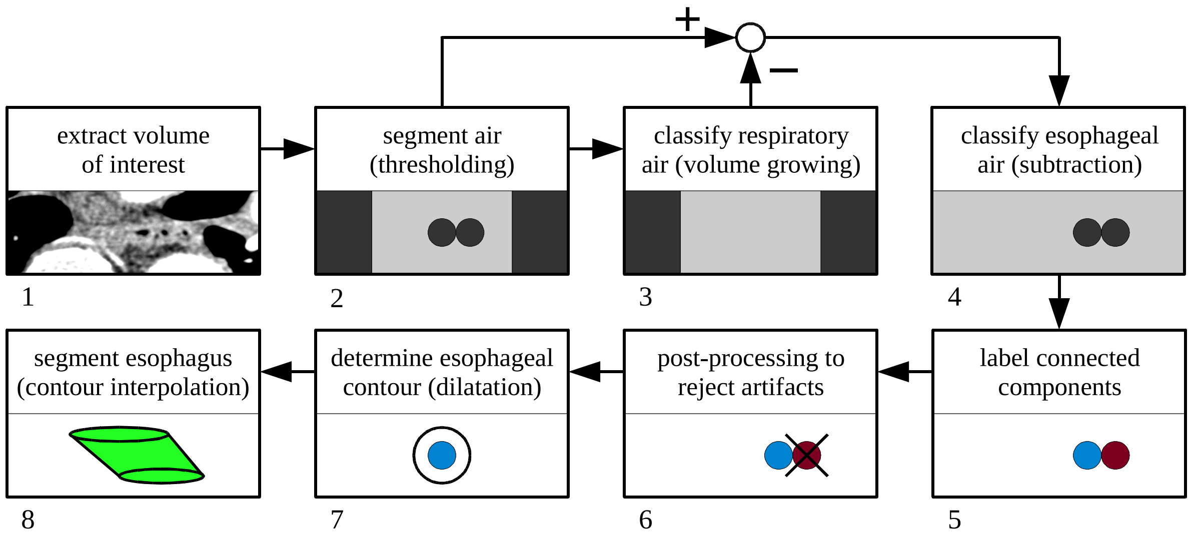

Fig. 1: Flow chart of the algorithm for automated 3D esophagus segmentation in CT images

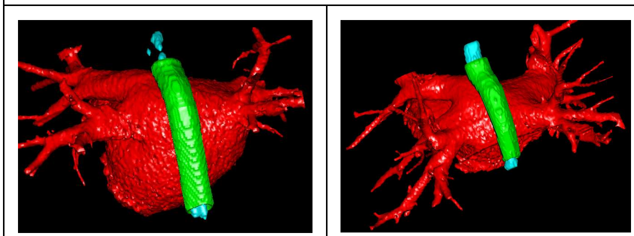

Fig. 2: Fully automated segmented esophagi (green) and intraesophageal air holes (blue) from two different CT data sets. The segmented left atrium is shown in red.

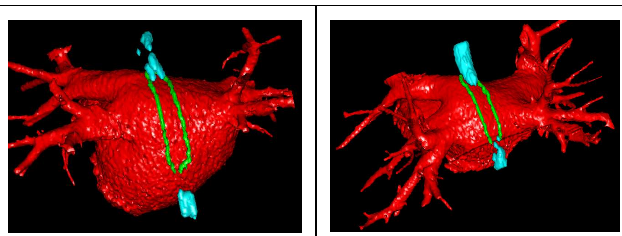

Fig. 3: Visualizations of the boundary of the atrial-esophageal contact area (green) that were determined from the segmentations shown in Fig. 2

Literature

[1] Pappone C et al. Atrio-Esophageal Fistula as a Complication of Percutaneous Transcatheter Ablation of Atrial Fibrillation. Circulation 2004;109(22):2724-26; **[2]** Rousson M et al. Probabilistic Minimal Path for Automated Esophagus Segmentation. In: Proc SPIE Medical Imaging. vol. 6144; 2006. p. 614449-4H; **[3]** Handels H. Medizinische Bildverarbeitung. Stuttgart: Teubner; 2000; **[4]** Kalender WA. Computed Tomography. 2nd ed. Erlangen: Publicis Corporate Publishing; 2005.