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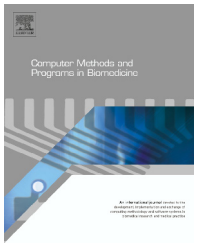

Measurements of the left atrium and pulmonary veins for analysis of reverse structural remodeling following cardiac ablation therapy

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ABSTRACT

Rationale and objectives: Geometric analysis of the left atrium and pulmonary veins is important for assessing reverse structural remodeling following cardiac ablation therapy. Most volumetric analysis techniques, however, require laborious manual tracing of image cross-sections. Pulmonary vein diameters are typically measured at the junction between the left atrium and pulmonary veins, called the pulmonary vein ostia, with manually drawn lines on volume renderings or in image slices. In this work, we describe a technique for making semi-automatic measurements of left atrial volume and pulmonary vein diameters from high resolution CT scans and demonstrate its use for analyzing reverse structural remodeling following cardiac ablation therapy.

Methods: The left atrium and pulmonary veins are segmented from high-resolution computed tomography (CT) volumes using a 3D volumetric approach and cut planes are interactively positioned to separate the pulmonary veins from the body of the left atrium. Left atrial volume and pulmonary vein ostial diameters are then automatically computed from the segmented structures. Validation experiments are conducted to evaluate accuracy and repeatability of the measurements. Accuracy is assessed by comparing left atrial volumes computed with the proposed methodology to a manual slice-by-slice tracing approach. Repeatability is assessed by making repeated volume and diameter measurements on duplicated and randomized datasets. The proposed techniques were then utilized in a study of 21 patients from the Catheter Ablation versus Antiarrhythmic Drug Therapy for Atrial Fibrillation Trial (CABANA) pilot study who were scanned both before and approximately 3 months following ablation therapy.

Results: In the high resolution CT scans the left atrial volume measurements show high accuracy with a mean absolute difference of $2.3 \pm 1.9\,cm^3$ between volumes computed with

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the proposed methodology and a manual slice-by-slice tracing approach. In the intra-rater repeatability study, the mean absolute difference in left atrial volume was $4.7 \pm 2.5\,cm^3$ and $4.4 \pm 3.4\,cm^3$ for the two raters. Intra-rater repeatability for pulmonary vein diameters ranged from 0.9 to 2.3 mm. The inter-rater repeatability for left atrial volume was $5.8 \pm 5.1\,cm^3$ and inter-rater repeatability for pulmonary vein diameter measurements ranged from 1.4 to 2.3 mm. In the patient study, significant ($p < .05$) decreases in left atrial volume and all four pulmonary vein diameters were observed. The absolute change in LA volume was $20.0\,cm^3$, 95%CI [12.6, 27.5]. The left inferior pulmonary vein diameter decreased 2.1 mm, 95%CI [0.4, 3.7], the left superior pulmonary vein diameter decreased 3.2 mm, 95%CI [1.0, 5.4], the right inferior pulmonary vein diameter decreased 1.5 mm, 95%CI [0.3, 2.7], and the right superior pulmonary vein diameter decreased 2.8 mm, 95%CI [1.4, 4.3].

Conclusions: Using the proposed techniques, we demonstrate high accuracy of left atrial volume measurements as well as high repeatability for left atrial volume and pulmonary vein diameter measurements. Following cardiac ablation therapy, a significant decrease was observed for left atrial volume as well as all four pulmonary vein diameters.

1. Introduction

In left atrial fibrillation (AF), the atria of the heart beat rapidly and asynchronously resulting in irregular heartbeats. It has been shown that patients with AF have increased left atrial volumes and pulmonary vein diameters [1,2], a process termed structural remodeling. Cardiac ablation therapy is a treatment strategy in which catheters are guided into the left atrium and used to created radiofrequency lesions in the myocardial tissue in order to interrupt the aberrant electrical signals causing the arrhythmia. Reverse structural remodeling has been shown to occur following ablation therapy with decreases in left atrial volume and pulmonary vein diameters [3–7]. To date, however, most analysis techniques of left atrial volume require labor intensive manual tracing of image cross-sections [4,8] or volumetric estimation using line measurements from orthogonal images slices [5,6,9]. Pulmonary vein diameters have also typically been measured with manual approaches using line measurements in image slices [2,6,10–13] or on volume renderings [3,4,14] as illustrated in Fig. 1.

In this work, we have developed a semi-automated approach for measuring left atrial volume and pulmonary vein diameters from high resolution CT scans. After extracting the left atrium and pulmonary veins as a single structure from the volumetric data, the pulmonary veins are separated from the body of the left atrium by interactively positioning a 3D cut plane at the pulmonary vein ostia. The cut plane is visualized simultaneously as a 3D plane in a volume view as well as lines in the three orthogonal image views. The oblique image which represents the ostial plane is also shown in an additional window. The combination of these visual cues allows the user to accurately position the plane based on both 3D and 2D anatomical information and the final diameter measurement is automatically computed in the oblique ostial image plane. The proposed techniques were validated to assess both accuracy against a manual slice-by-slice tracing approach and repeatability across duplicated datasets. We note that preliminary work on the segmentation and validation studies have been previously reported in conference form [15,16].

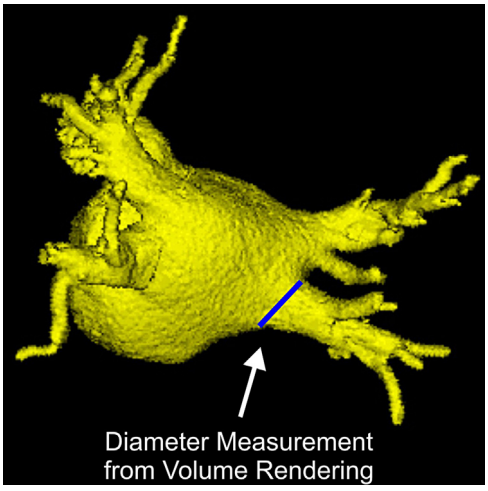

Fig. 1 – Example of measuring the right inferior pulmonary vein ostium using lines drawn manually on a volume rendering of the left atrium and pulmonary veins.

The proposed methodologies are utilized to conduct an analysis on a collection on 21 patients from the Catheter Ablation versus Antiarrhythmic Drug Therapy for Atrial Fibrillation Trial (CABANA) pilot study who were scanned both before and approximately three months following ablation therapy. Consistent with previous studies [4–7], we observed significant decreases in left atrial volume and all four pulmonary vein diameters following ablation therapy.

2. Methods

2.1. Segmentation and analysis

The segmentation methodology utilizes a semi-automatic approach in which an analyst interacts with a user interface developed specifically for this application, shown in Fig. 2. On the left side of the user interface is a control panel

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