Volumetric Identification of Left Atrial Fibrosis from Delayed Enhancement Magnetic Resonance Imaging in Atrial Fibrillation: Preliminary Results

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Abstract

Delayed gadolinium enhancement magnetic resonance (DE-MR) imaging can be used for in vivo detection of left atrium (LA) fibrosis and scarring, whose identification is important for atrial fibrillation (AF) treatment. This study presents a new tool for 3D visualization of cardiac LA fibrosis based on DE-MR imaging and its qualitative validation by comparison with electro-anatomic mapping (EAM). Angio-MR (MRA) and DE-MR images were acquired and registered applying an affine transformation. Automatic LA segmentation was obtained from MRA images. Color-coded gray level intensities of DE-MR images were used as texture for the LA 3D surface model. The comparison in 4 patients between our 3D surface model and the 3D EAM confirmed the qualitative correspondence between the low-potential areas and the high-enhanced areas in DE-MR. Preliminary results on volumetric visualization of LA fibrosis based on DE-MR and MRA data processing have shown promising results and simple thresholding of our color-coded map could lead to a fast 3D quantification and localization of LA fibrosis.

1. Introduction

Atrial fibrillation (AF) is the most common sustained arrhythmia afflicting more than 6 million people in America and Europe and it is a major risk factor for stroke and congestive heart failure and death [1].

Rhythm control strategies using antiarrhythmic medications have shown no significant benefits for the treatment of AF, therefore a growing interest is focused in catheter ablation to improve treatment efficacy and outcomes. Unfortunately, reported success rates for AF ablation vary widely between 40%, and 70% [2] and suggest the need for better patient selection criteria to reduce the recurrence rates of AF ablation. The low success rates for AF ablation motivate the increasing interest in understanding the mechanism underlying AF.

Recently, several studies investigating the relationship between left atrium (LA) substrate and AF, reported an association between AF and the presence of LA wall fibrosis [3]. However, whether fibrotic transformation is the cause or the consequence of AF remains unclear. Some studies support the hypothesis that structural remodeling causes the formation of circuits needed for re-entry, causing and perpetuating atrial arrhythmia [4]; other studies show AF causes an increase in the collagen content and therefore contributes to fibrosis formation in the LA wall [5].

On the contrary, a well-established knowledge regards LA wall areas characterized by the presence of fibrosis correspond to low-voltage tissue in the electro-anatomic map (EAM) [6]: fibrotic tissue visualization, location and extent seems to be directly correlated with the amount of low voltage tissue in EAM.

Delayed gadolinium enhancement magnetic resonance (DE-MR) imaging is a promising, non-invasive and potentially more accurate alternative to fibrosis assessment. Is has been extensively used to assess fibrosis in left ventricular wall and only few studies tested this imaging technique for fibrosis assessment in the thin LA wall in AF patients for selecting suitable candidates for ablation [12,13]. Unfortunately DE-MR images are characterized by low signal-to-noise ratio and their automated processing for LA surface detection is a challenging task.

The aim of study was to develop a new tool for 3D visualization of cardiac LA fibrosis on 3D LA surface obtained from angio-MR (MRA) in patients with AF and its qualitative validation by comparison with EAM.

2. Methods

2.1. Study population

Four consecutive patients (age 60±6yrs) candidates for AF ablation at the Cardiology-Cardiological Intensive Care Unit, Bufalini Hospital in Cesena, Italy, were selected for this preliminary study.

All patients gave written informed consent in

agreement with the local Ethics Committee.

2.2. Image acquisition

Acquisition was performed using an Achieva 1.5T (Philips Medical System, Best, The Netherlands). Anatomical images of the atrium were obtained using a contrast enhanced 3D fast low angle shot sequence during a first pass of contrast agent intravenous injection (Multihance, Bracco Diagnostics Inc., Princeton, NJ, USA) of a dose of 0.1mmol/kg (2 ml/s injection rate) followed by a 20 ml saline flush.

DE-MR was used to identify fibrosis. Images were acquired 15 minutes after contrast agent injection using a 3D inversion recovery prepared, respiration navigated, ECG-gated, gradient echo pulse sequence. Acquisition parameters were as follows: volume with voxel size 1.2x1.2x1.5 mm, slices for slab60-80, TR/TE=6.3/2.3 ms, inversion time <310 ms, flip angle 22° with fat saturation, bandwidth 220 Hz/pixel and GRAPPA with R=2 and 62 reference lines. Scan time was between 15 and 19 minutes depending on subject respiration and heart rate.

For each patient, a 3D voltage map of the LA was recorded using the cardiac mapping system EnSite Velocity (St. Jude Medical Inc., Saint Paul, MN, USA), acquired in high quality mode and registered onto anatomical reconstruction of the LA based on fluoroscopy.

2.3 Image processing

Image processing was performed following the workflow described in figure 1. We firstly registered MRA and DE-MR images (figure 1a) by applying a multi-resolution affine registration algorithm based on mutual information as a similarity criterion [8]. The result of this step was the DE-MR dataset in the same coordinate system of the MRA dataset.

Then, MRA images were processed to detect 3D LA surface using a custom tool developed in MatLab (Mathworks, Natick, MA; USA) (figure 1b). To obtain automatic LA segmentation from MRA images, we applied a 2D segmentation method based on the intra-class variance minimization followed by a density-based spatial clustering to reconstruct LA in 3D (figure 2).

Otsu's segmentation [9] assumes that the image contains two classes of pixels and calculates the optimum threshold separating the two classes so that intra-class variance is minimal. This procedure resulted in binary images in which only one of the detected regions of the foreground pixels belongs to LA. In the central image of the 3D dataset we manually selected one point inside the LA and, exploiting this information, we applied a density-based clustering algorithm [10]

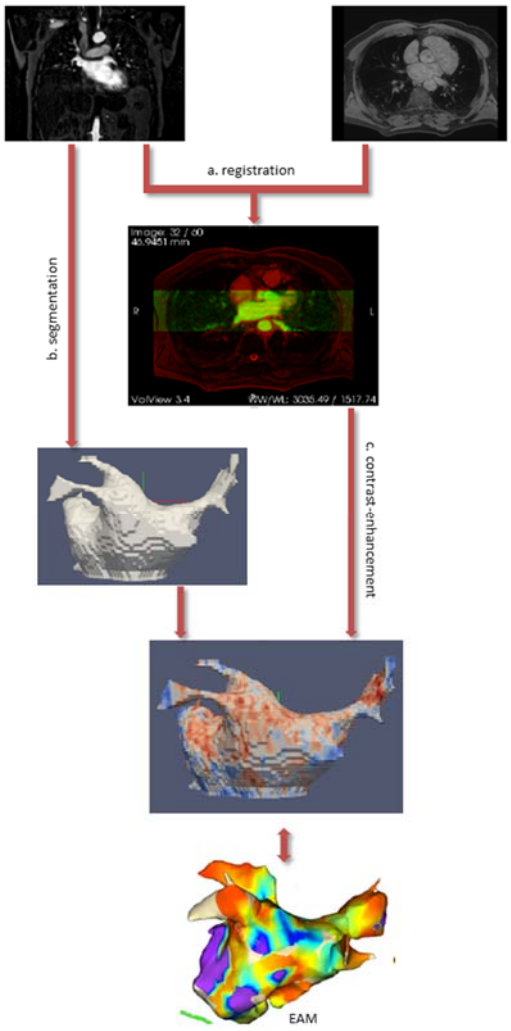

Figure 1. Image processing workflow.

selecting between the 2D labeled connected regions, the one whose center is the closest to the selected point, within a predefined, fixed distance. The edges of these regions are then interpolated in the third dimension using a distance map-based algorithm.

Once the 3D LA surface was detected we overlapped the corresponding intensity gray level information derived from the DE-MR images (figure 1c). To avoid possible errors due to inaccuracies in the segmentation step we used the mean gray level intensity information belonging to a fixed thickness of 3 pixels, around the LA detected contour.

To better visualize fibrosis location and extent, the texture was visualized applying a color-coded scale and a thresholded color-coded scale (figure 3). Visualizations were performed using Paraview (Kitware Inc. New York, NY, USA).

The computed 3D model showing the cardiac tissue

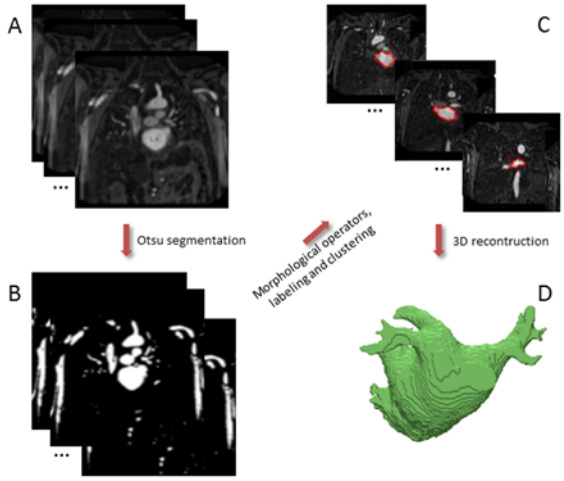

Figure 2. 3D segmentation workflow: A. MRA images; B. Otsu's segmentation result; C. detected LA regions; D. final 3D LA surface.

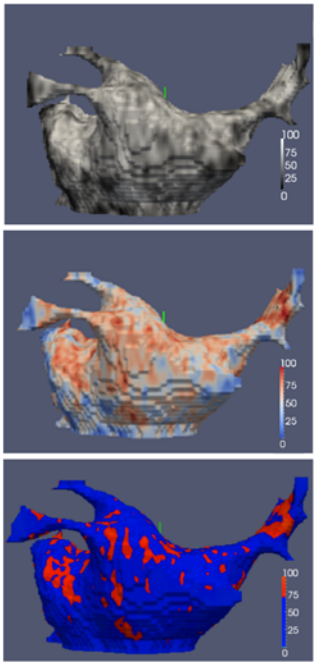

Figure 3. 3D LA surface visualization using gray level intensity values (top), a color-coded (mid) and a thresholded color-coded scale (bottom).

and fibrosis distribution was visually compared with the voltage values in EAM.

3. Results

Analysis time required for performing data registration, segmentation and 3D model visualization was < 3 min.

A result of the registration step is shown in figure 4,

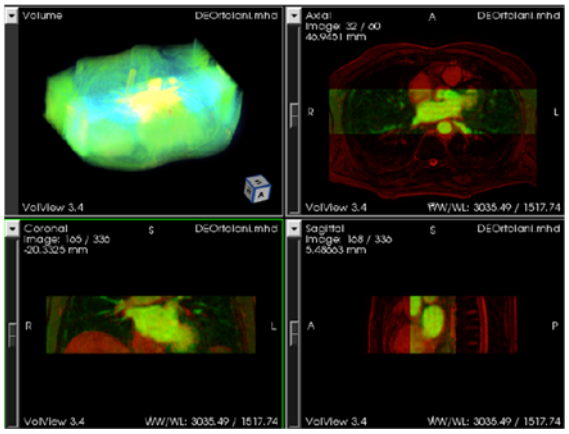

Figure 4. Result of the affine registration in one patient in three orthogonal planes. In red we show the MRA images, in green the DE-MR images.

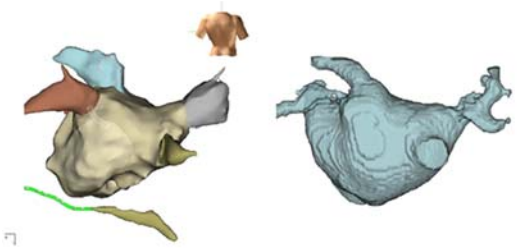

Figure 5. 3D surfaces obtained in one patient applying our method (right panel) and the 3D anatomical map exported from Ensite Velocity software (left panel).

in one patient.

The comparison between the 3D surfaces obtained in one patient applying our method and the 3D anatomical map exported from Ensite Velocity software is shown in figure 5.Two examples of the correspondence between our 3D LA model including fibrosis information and the corresponding voltage maps are shown in figure 6.

4. Discussion and conclusion

We developed a workflow for 3D visualization of cardiac LA fibrosis on a 3D LA model derived from MRA, in patients with AF.

Preliminary results in only 4 patients included the comparison, pre and post AF ablation, between the fibrosis maps from MR and EAMs. Visual fibrosis identification confirmed the qualitative correspondence between the low-potential areas in EAM and the high-enhanced areas in MR. Therefore, integration between the information derived from DE-MR and MRA is feasible and our processing procedure has shown results deserving additional investigations, including a

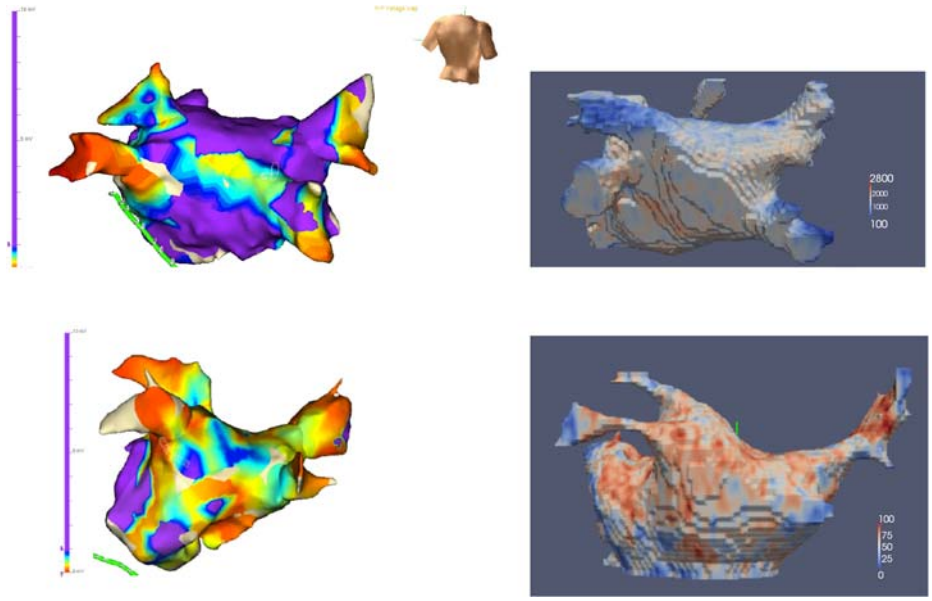

Figure 6. Qualitative comparison between the 3D LA surfaces with the fibrosis information as a texture and the corresponding EAMs in two patients, pre ablation (upper row) and post ablation (lower row).

quantitative validation of each step of our processing.

Several interesting developments are directly available once validation is performed; for example the import of an accurate morphological LA 3D model based on MR imaging in the mapping system and a fast 3D quantification of LA fibrosis location and extent simply thresholding our color-coded map could be very useful to improve the ablation strategy. In addition the investigation of the relationship between fibrosis and electrical rotors development, by adding to the model the activation patterns recorded in AF, could give further insights on AF mechanisms.

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