Regional Segmentation of the Left Atrium: A Preliminary Test in Atrial Fibrillation Patients

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Abstract

Differently from the left ventricle, the regional segmentation of the left atrium (LA) is still a matter of investigation having the LA attracted the interest of the scientific community only recently. In this study, a new automatic approach for LA regional segmentation was proposed. An approach to divide left atrium into well-defined anatomical regions to better evaluate the effects of AF on different regions of left atrium is proposed. Up to now, we have tested this approach on 10 AF patients. Our algorithm rightly divides the LA in all the 10 patients and in future, these anatomical regions can be helpful to assess the deformation of left atrial tissues in different parts of LA.

1. Introduction

Atrial fibrillation (AF) is known to interfere with the normal mechanical functioning of the atrium, and its effects on cardiac function may persist even when patients are in sinus rhythm. Studies have shown that dilatation of the atrium occurs early in AF and is related to cardiovascular morbidity and mortality [1]. Contractile and structural remodeling also occur in AF, leading to significant fibrosis, hypertrophy and myolysis; reduced left atrial (LA) contractility and impaired transport function [2]. Relatively few studies have formally examined the effect of AF on atrial function. Several reports have shown a decreased LA ejection fraction in patients with AF [3].

Moreover, frequent AF episodes damage LA tissue by causing electrical and structural remodeling [4]. This spatial variation in remodeling creates regional heterogeneity in both structure and function. Structural heterogeneity also arises from catheter ablation, which permanently scars atrial tissue. Given the limitations of anti-arrhythmic drugs [5], catheter ablation has become the primary AF therapy [6] and has been proposed as a first-line treatment [7]. Pulmonary vein isolation (PVI) has become an accepted treatment for AF [8]. The efficacy of PVI is sometimes insufficient, and atrial substrate modification of target specific AF signals indicating the substrate responsible for AF perpetuation has been proposed [9,10]. Complex fractionated atrial electrograms (CFAEs), which are electrograms that demonstrate continuous fractionation and very short cycle lengths during AF, may represent the substrate of AF [9,10]. In addition, atrial sites that represent local electrograms with high-dominant frequencies (DFs) may be associated with AF maintenance [11-13].

We hypothesize that, in such scenario, the integration of regional structural and functional information may improve the characterization of AF mechanisms. Unfortunately, the regional segmentation of the LA chamber is still a matter of investigation and no recommendation suggesting a standard approach exists. In this paper, we propose a new approach to automatically divide the LA into seven well defined regions, which are, anterior, posterior, roof, inferior, lateral, septal and LAA, and these regions can be used to evaluate the regional mechanics of the LA in AF patients.

2. Material and Methods

2.1. Image acquisition

CT imaging data of the LA were acquired in sinus rhythm from a Philips Brilliance 64 CT scanner (200 axial slices, 0.4 mm x 0.4 mm pixel size, 1 mm slice thickness).

2.2. Image segmentation

To segment the DICOM data obtained from CT and define the LA anatomical model, we used an active contour algorithm previously developed in Matlab environment. First, we restricted the segmentation to LA only by defining a region of interest (ROI) and then initialized active contour and stopped the evolution when the LA came inside the contour. At the end, we saved the resulted surface in stereolithography (STL) format.

2.3. Post processing of surfaces

Before starting the regional segmentation, we applied Laplacian smoothing on the LA surfaces and defined cutting planes on all the four pulmonary veins (PVs) and on the mitral valve (MV). For this purpose, we used the open-source Autodesk Meshmixer software. We manually applied cutting planes to exclude tissues from PVs and to get ostium for PVs and MV. Figure 1 shows the output

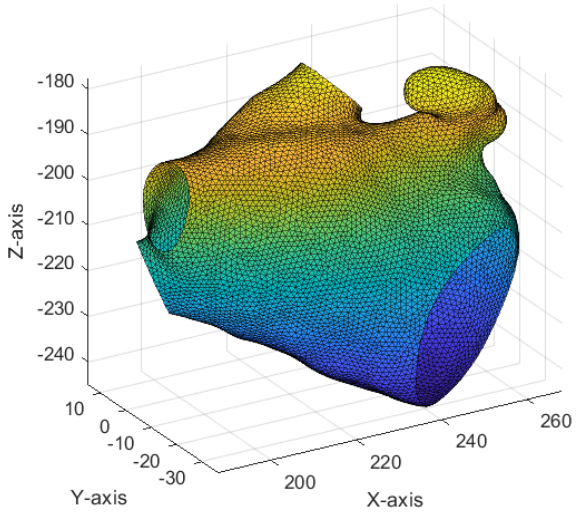

Figure 1. Anterior view of LA anatomical model

surface resulting from the post-processing in one patient.

2.4. Regional segmentation of Left Atrium

In the first step of the regional segmentation, we excluded the left atrial appendage (LAA) from the LA applying a thresholding approach based on the shape diameter function. [14]. Then the algorithm calculated the barycenter of all the four PVs, the MV and the LAA, and then the weighted barycenter of PVs by considering their area. The latter identified the MV by considering its area as well as its location: we assumed that MV has the biggest area amongst all the openings, and its barycenter is the farthest one.

We drew the long axis of LA by connecting the barycenter of MV and the weighted barycenter of PVs. Long axis is an important parameter because whenever we draw a line in space, we project that line onto the LA in the direction of long axis. The long axis can be seen in figure 2 as the red dotted line.

To distinguish the barycenter of each PV, we manually identified the barycenter of the left superior pulmonary vein (LSPV) and with respect to this, our algorithm automatically identified the barycenter of left inferior pulmonary vein (LIPV), right superior pulmonary vein (RSPV) and right inferior pulmonary vein (RIPV).

To initiate regionalization, we connected LSPV and LIPV barycenters, then the barycenters of LSPV and RSPV and finally the barycenter of RSPV to the barycenter of RIPV, these lines (blue lines in figure 3 were projected onto the LA surface in the direction of the midpoint of long axis.

To define the roof region, we drew a line connecting the barycenter of RSPV and the point on the ostium of RSPV generated by the projection of the line connecting the

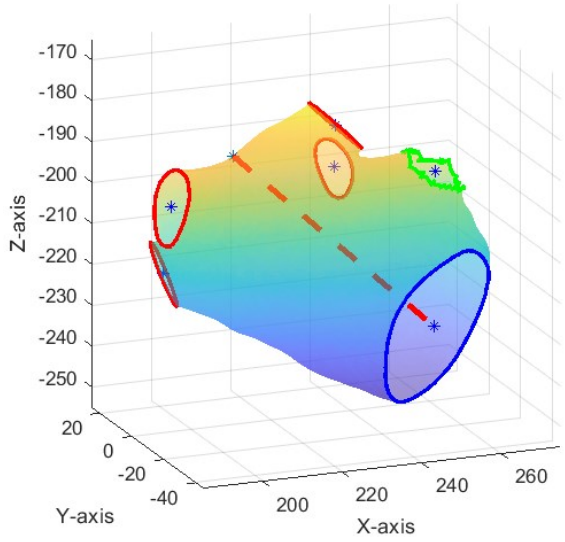

Figure 2. Long axis is represented by the red dotted line which connects MV barycenter with the PVs weighted barycenter. The PVs ostium is in red, the MV ostium is in blue and the LAA ostium is in green.

barycenters of RSPV and LSPV. Then we rotated this line by 90 degrees in clockwise direction and received a second point on the ostium of RSPV (black points in figure 3). We implemented the same approach on the LSPV but rotated the line by 90 degrees in counterclockwise direction. By doing this, we generated two new points on the ostium of RSPV & LSPV and by connecting them we obtained a new projection line that defines the roof region as shown in figure 3.

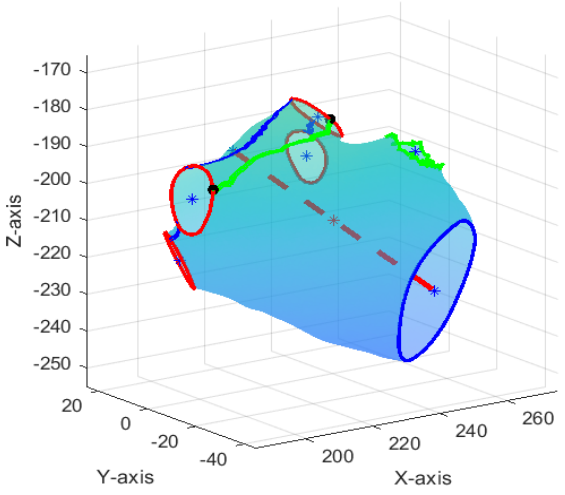

Figure 3. The green line is the new projection line that, together with the blue line above, define the roof.

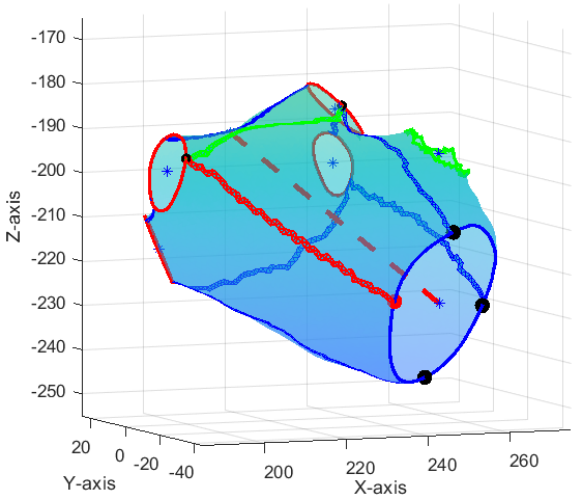

Figure 4. Three new points on the MV ostium in black and the projections in blue to the respective PVs. The red point is generated by connecting the second point on the RSPV ostium with the MV barycenter.

To draw the boundaries between anterior and septal regions (red line in figure 4), we connected the second point on the ostium of RSPV to the barycenter of MV. By doing this, we found one point on the MV ostium (red point) and, by rotating this point in clockwise direction at [90 90 90] angles, we generated three more points on the MV ostium as shown in figure 4. Finally, we connected these three points to the barycenter of LSPV, LIPV and RIPV respectively defining three other regions, which are septal, anterior and lateral.

To draw the boundaries between posterior and inferior regions, we took the points previously obtained on the ostium of LIPV and RIPV and connected them with a straight line. Then we projected the line onto the LA surface in the direction of midpoint of long axis. Moreover, the LAA was treated as a different region from the rest of LA.

By applying this approach, we labelled seven well defined regions, namely posterior, anterior, roof, inferior, lateral, septal and LAA.

3. Results

In our study, we considered 10 AF patients in which the size and the anatomical structure of the PVs varied as well as the location of the LAA, but still the algorithm ran on all cases and successfully divided the LA into seven regions. Figure 5 shows the final segmentation of LA.

An expert electrophysiologist graded the result of regional segmentation as: unacceptable, poor, fair and good. The grading of the expert was fair and good in 3 and 7 patients, respectively.

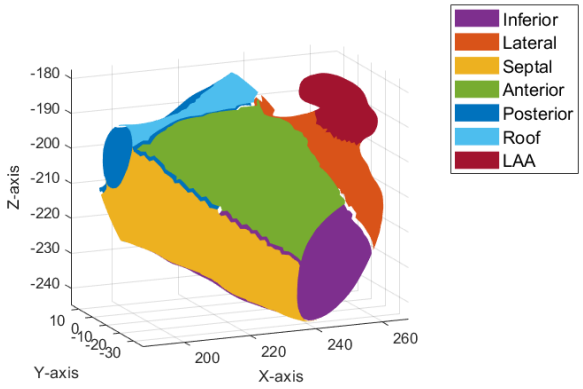

Figure 5. Final regional segmentation of LA.

4. Discussion

This study presents a new approach to automatically divide the LA into seven anatomical regions.

It represents a first step towards the quantification of regional functional and contraction indices of the LA. By considering these regions, different mechanical functions of LA can be evaluated separately. This approach can also be helpful to monitor regional mechanics during catheter ablation procedures. Also, using this algorithm, it is possible to 3D print individual regions of LA to perform surgical simulation as well as to understand and elaborate structural remodeling of different regions of LA.

Our approach successfully faced the variability in LA anatomy in the 10 patients we enrolled. However further testing is required to confirm these results. We hypothesize the results are dependent on the anatomy, in particular, of PVs. In some cases, we found that left PVs are very close to each other and form a common trunk and, for a very few cases, it also happened for the right PVs. But our algorithm was always able to distinguish each PV and proceeded to calculate their barycenter. Regarding the number of PVs, our algorithm provides well-defined regions when the number is four, which is the most common case but, if the number varies, it may require manual correction to proceed to the identification of different regions.

Localization of the LAA is also one of the crucial tasks since, in AF cases, most of the times blood clots originate in the LAA. The position of the LAA depends on the ostium and the barycenter of LAA. We designed our algorithm so that, if the ostium is totally included in the lateral wall, then the LAA belongs to lateral region. On the other hand, if the ostium is completely on the anterior wall, which is rare, then the LAA will be included in the anterior region. In other cases, if the barycenter of LAA lies on the border of anterior and lateral regions, then it will be partially included in both regions.

5. Conclusion

To conclude, the approach presented in this paper can automatically divide the LA into seven well defined anatomical regions which also includes LAA, PVs and MV and these regions can be used to assess and quantify regional functioning of LA.

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