Development of 3D Patient-specific Models for Left Atrium Geometric Characterization to Support Ablation in Atrial Fibrillation Patients

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Abstract

Radiofrequency catheter ablation (RFA) is an important and promising therapy for atrial fibrillation (AF) patients. About 50% of patients present AF recurrence during the first three months of follow-up. Several studies have been performed to assess the relationship between left atrium (LA) volume and AF recurrence following RFA. In fact, atrial enlargement is a consequence of AF and these changes may facilitate the induction of AF. In this study a fully automated approach for LA segmentation with and without pulmonary veins (PVs) from magnetic resonance angiography was implemented and two 3D LA patient-specific models were obtained. LA volumes were compared with volumes from manual segmentation (y=0.92x+4.9, r=0.97, bias=-1.8ml (-2.1%), SD=5.6ml (6.5%), mean percentage difference=-1.8%±7.4%). The developed procedure provides (1) a 3D patient-specific LA model without PVs in order to characterize LA size and (2) a 3D patient specific model including PVs to assist ablation procedure. Future developments of this work include the analysis of the relationship between LA size and RFA success and the use of LA volume as a predictor of AF recurrence.

1. Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia affecting 2.2 million people in the USA and 4.5 million in Europe. Its impact on health care is substantial and AF is associated with a 5 fold increase in risk of stroke, and a doubling of death rate [1]. Unfortunately, its therapy remains suboptimal. Radiofrequency catheter ablation (RFA) is a non-pharmacological therapy that aims to restore sinus rhythm by eliminating tissue causing AF, and is more effective than medications. Nevertheless its efficacy is limited, mainly because the mechanisms that sustain AF are not yet clearly identified.

Nowadays ablation procedure is guided by an electro-anatomical map (EAM) consisting in a rough anatomical model of the LA including PVs on which electrical information is mapped. The construction of the EAM is a time-consuming, potentially imprecise and cumbersome procedure.

Conventional RFA approach consists in isolating the left and right pulmonary veins in pairs. This approach appears to be inefficient, resulting in a low success rate also in patients who have intermittent episodes of AF and it is not clear if additional ablation lesions may improve the outcome of the RFA procedure. In this scenario, a more detailed LA anatomical model derived from magnetic resonance angiography (MRA), including a better identification of PVs, could assist RFA procedure.

Another important aspect is the role of LA volume as a predictor of AF recurrence after RFA procedure and its relationship with RFA success rate. It is well known that atrial enlargement is a common consequence of AF, causing cellular, anatomic, and functional remodelling of the atrium. These changes may facilitate the induction and perpetuation of AF.

Over the last decade, a series of studies have been performed to assess the relationship between LA anterior-posterior diameter estimated with transthoracic 2D echocardiography and AF recurrence after RFA [2]. These studies showed inconsistent results. Abecosis et al. [3] demonstrated that LA volume was related to the outcome of radiofrequency ablation, whereas the diameter was not. Therefore, accurate assessment of LA volume using a three-dimensional imaging modality is essential for improvement of AF patient selection for RFA.

Accordingly, this study aimed at developing a unified, fully automated approach to build a 3D patient-specific LA model including PVs in order to provide an accurate anatomical guide during RFA and a 3D patient-specific LA model without PVs in order to characterize LA volumetry.

2. Materials and methods

2.1. Patients

Eleven patients referred for AF ablation were included in the study. They underwent pre-procedural MRA. The main clinical characteristics are summarized in table1. In some patients ablation procedure outcome was available.

Table 1. Patients cohort characteristics.

	Age	Gender	AF type	Previous ablation procedures	Follow-up (months)	Recurrence o AF
Patient 1	50	M	Paroxysmal	1	12	none
Patient 2	57	M	Paroxysmal	none	2	none
Patient 3	52	M	Paroxysmal	none	3	yes
Patient 4	48	F	Paroxysmal	none	/	/
Patient 5	57	M	Paroxysmal	none	/	/
Patient 6	59	M	Persistent	none	/	/
Patient 7	71	M	Paroxysmal	none	/	/
Patient 8	64	M	Paroxysmal	none	3	none
Patient 9	67	M	Paroxysmal	none	/	/
Patient 10	44	M	Paroxysmal	none	11	none
Patient 11	59	M	Paroxysmal	none	24	none

2.2. Data acquisition

Images were obtained by using a 1.5T MRI scanner (Philips Medical System, Achieva) and a 3D spoiled gradient recalled (GR SP PFP). Contrast enhanced 3D MRA images were acquired (Figure 1) (echo time: 1.12 ms, repetition time: 3.74 ms, flip angle: 25°, in-plane resolution 0.7x0.7 mm and slice thickness 3 mm with 1.5 overlap, gadolinium injection 0.1 mmol/kg +20 ml saline flush).

2.3. Segmentation algorithm

The fully automated segmentation algorithm was based on a 2D edge-based level set approach guided by a phase–based edge detector (Figure 1). The phase was obtained by the 2D monogenic signal [4].

The initialization of the level set function was obtained by applying Otsu's method [5] resulting in a rough detection of LA boundaries.

MRA image segmentation was automatically applied to all 2D MRA acquired slices in which LA was visible.

Due to problems in acquisition triggering, in some images both ventricle and atrium were present. Therefore, by considering image gray level intensity distribution, the evolution of the level set function was forced not to leak from the LA chamber, being the gray level values in the left ventricle characterized by lower intensities. From the 2D detected contours including the PVs (Figure 2, left panel), the 3D LA model was obtained (Figure 2, middle panel).

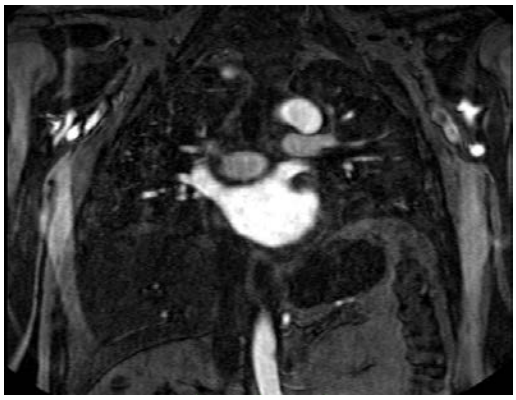

Figure 1. Example of MRA image

PVs deletion was required to compute LA volume. Thinning morphological operator was applied to each detected contour and the 3D LA model without PVs was obtained by removing the spurious segments corresponding to the PVs (Figure 2, right panel).

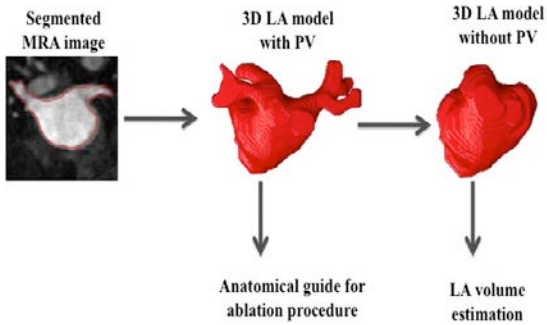

Figure 2. Workflow of the developed approach; left panel: final detected contour in a 2D MRA image; middle panel: 3D patient-specific LA model including PVs; right panel: 3D patient-specific model without PVs.

LA volume estimates were obtained by applying geometric approximation, considering MRA spatial resolution, slice thickness and spacing between slices.

LA volume reference values were obtained by manual tracing of LA boundaries by an experienced radiologist. In order to perform manual contouring, an in-house toolbox for manual segmentation was implemented.

LA volume estimates were compared with LA volume reference values by linear regression and Bland-Altman analysis.

The automatic algorithm and the toolbox for manual segmentation were developed in Matlab environment (v.R2014a, Mathworks, Natick, MA).

3. Results

Automatic segmentation was feasible in all study

subjects.

Time required for the analysis was about 4 minutes for the 3D LA model with PVs and about 5 minutes for the 3D LA model without PVs on a 2.5 GHz, Intel Core i5 computer with 8 GB RAM.

An example of the 3D patient-specific LA models with (red surface) and without (blue surface) PVs is shown in Figure 3.

Median LA volume was 95ml (ICQ: 70-100ml) from manual analysis and 91ml (ICQ:73-98ml) from the automated approach.

Results of the regression and Bland-Altman analyses between LA volume estimates and corresponding references are shown in Figure 4 (y=0.92x+4.9, r=0.97, bias = -1.8ml (-2.1%), SD=5.6ml (6.5%)).

Mean percentage difference was -1.8%±7.4%; mean percentage absolute difference resulted in 5.9%±4.4%.

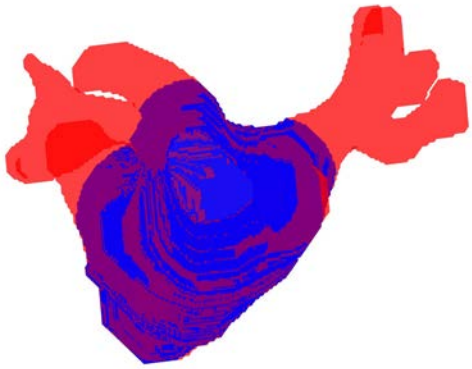

Figure 3. 3D patient-specific LA model with (in red) and without (in blue) PV geometry.

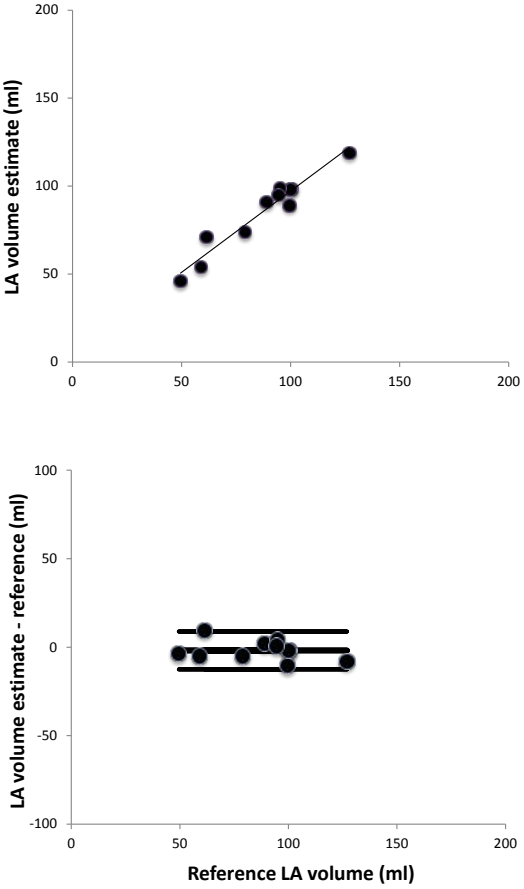

Figure 4. Linear regression (top panel) and Bland Altman analysis (bottom panel) between the LA volume estimates and corresponding references.

4. Discussion and conclusion

In AF patients, an accurate 3D patient specific model could assist RFA improving ablation outcome and, at the same time, provide quantitative information regarding LA volumetry, predictive of AF recurrence.

LA segmentation is a challenging task due to high variability in LA anatomy. In addition PVs detection is mandatory for ablation guidance and voltage or activation mapping, whilst PVs should be excluded for LA volume computation.

In this study, a unified and fast workflow has been developed allowing computation of 3D patient-specific LA models (with and without PVs) useful in these two scenarios.

Indeed, PVs removal from 3D patient specific model was effective, since preliminary results on a small group of 11 patients show volume computation is accurate with tight limits of agreement and small percentage errors.

Future developments include further validation on a large number of patients. In addition, the hypothesis that a more realistic LA anatomy detection could improve RFA procedure, should be verified by the integration of the 3D patient-specific LA model from MRA with voltage information acquired during ablation procedure. Moreover, the assessment of the relationship between LA size and successful RFA outcome to better understand the link between LA volume and AF recurrence will be a future line of research.

References

[1] Harsha V. Ganga, Sanjeev U. Nair, Venkata K. Puppala, Wayne L. Miller. Risk of new-onset atrial fibrillation in elderly patients with the overlap syndrome: a retrospective cohort study. J Geriatr Cardiol. 2013; 10(2): 129–134.

[2] Berruezo A, Tamborero D, Mont L, Benito B, Tolosana JM, Sitges M, Vidal B, Arriagada G, Méndez F, Matiello M, Molina I, Brugada J. Pre-procedural predictors of atrial fibrillation recurrence after circumferential pulmonary vein

ablation. Eur Heart J. 2007;28(7):836-41

[3] Abecasis J1, Dourado R, Ferreira A, Saraiva C, Cavaco D, Santos KR, Morgado FB, Adragão P, Silva A. Left atrial volume calculated by multi-detector computed tomography may predict successful pulmonary vein isolation in catheter ablation of atrial fibrillation. Europace 2009;11(10):1289-94.

[4] Felsberg M, Sommer G. The monogenic signal. IEEE Transactions on Signal Processing 2001; 49: 3136-3144.

[5] Otsu N. A threshold selection method from gray-level histograms. IEEE Trans Sys, Man Cyber 1979; 9(1): 62–66.

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