

# Automated Detection of Left Atrium Boundary in Intracardiac Echocardiography During Atrial Fibrillation Ablation

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## Abstract

*Intracardiac echocardiography (ICE) is used during radiofrequency ablation (RFA) of atrial fibrillation to visualize and reconstruct left atrium (LA) anatomy and catheter placement, as well as to monitor potential complications, including the most harmful esophageal injuries. However, esophagus' dynamic interface with LA posterior wall (LAPW) can be only roughly depicted by any available echo-based method. In clinical practice, at best, LAPW contour is manually traced (MT) on ICE images by the cardiologist, a procedure which is cumbersome and time-consuming. Accordingly, the present study aimed detecting LAPW position automatically by ICE during RFA. To identify LA borders a procedure based on level-set method and pixel clustering was applied. Algorithm was tested on 9 ICE acquisitions. Two series of LA contours were compared with MT LA boundaries by linear regression, Bland-Altman analysis, Dice coefficient and Hausdorff distance. Mean analysis time was 1 sec/frame. Detected contours were fairly concordant with MT ones. The developed technique permits automated and accurate detection of LAPW and may be the preliminary step towards additional analysis including dynamic quantification of esophagus real-time position' changes and its distance from the LAPW.*

## 1. Introduction

Radiofrequency transcatheter ablation (RFCA) therapy is widely used to treat atrial fibrillation (AF), which is a cardiac arrhythmia characterized by a very rapid and uncoordinated electrical activity within the atria. It causes loss of atrial systole, atrial dilatation, slowing of intratrial blood mass and irregular and often fast ventricular rate, which together increase the risk of cardioembolic stroke, heart failure and death [1]. Percutaneous RFCA aims to suppress AF by ablating both focal sources and critical circuits which trigger and maintain the arrhythmia in

atrial tissue. Generally, RFCA is performed in an electrophysiology laboratory under fluoroscopic guidance. Electro-anatomical mapping systems, such as the CARTO system (Biosense Webster, Diamond Bar, CA, USA), are used to reconstruct the 3D left atrial geometry and to guide real-time intracardiac catheter placement and RF delivery [2,3]. Intracardiac echocardiography (ICE) can be integrated with the electro-anatomic maps and gives unique real-time anatomical information about all closely-located pericardiac structures, like pericardium, aorta and esophagus [4,5]. By the constant direct visualization, potential complications can be monitored, including the most harmful esophageal injuries, which may lead to atrio-esophageal fistula. This ominous event represents the second most common cause of mortality related to RFCA of AF [6].

In clinical practice, the exact position of the LA posterior wall (LAPW) is monitored by manually tracing ICE images which are transferred on 3D electroanatomic map. This procedure is imprecise, cumbersome and time-consuming.

Accordingly, the present study aimed at automatically detecting LAPW position by ICE during RFA, as a first step for tracking real-time esophageal-atrial spatial relationship and quantitative assessment of the esophagus position and distance from the LAPW .

## 2. Methods

In this section LA borders detection procedure is described. The workflow is shown in Figure 1.

### 2.1. Images acquisition

Nine ICE sequences were acquired in the Electrophysiology Laboratory of Santa Maria delle Croci Hospital in Ravenna, Italy, during AF ablation procedures. Image sequences were stored on an echographic system (ASCUSON Cypress plus, Siemens), then exported in *avi* format using a magnetic optic device

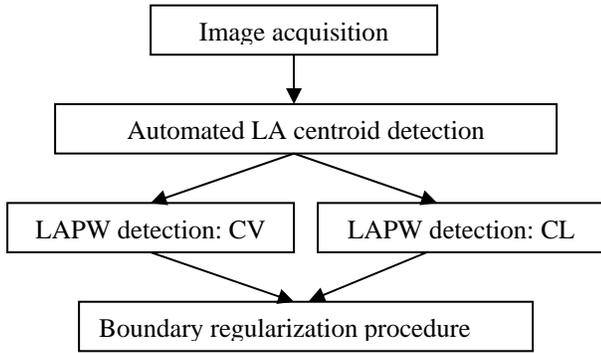


Figure 2. Workflow of the proposed method

(DynaMO 1300U2, Fujitsu).

An algorithm was developed to get each frame from the acquired sequence. Images were acquired when both the atrium and the esophagus were visible in the echo scan.

Because of the presence of noise and artifacts in the LA cavity, acquired sequences were divided into two classes: high noisy images, characterized by high presence of noise inside the LA chamber, and low noisy images, characterized by very low noise inside the chamber (Figure 2).

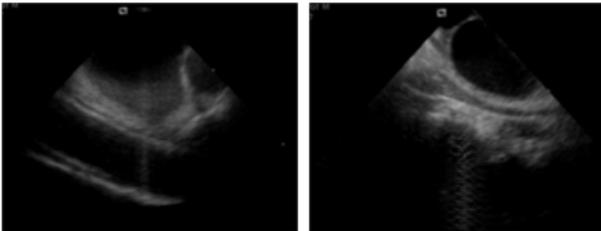


Figure 1. Examples of two images affected by much noise (left panel) and little noise (right panel).

Two different segmentation methods were developed to detect the LAPW in each class of images. The choice of the best method for LAPW detection was performed by visual assessment by the operator.

## 2.2. Automated LA centroid detection

As a first step for detecting LA boundaries, a mask corresponding to the echo scan was created to limit the working area (Figure 3B).

Otsu's method was applied to identify the darkest region within the mask. The Otsu method performs an automated thresholding segmentation based on the image histogram. Two classes separation is achieved calculating the optimal threshold by minimizing the intra-class variance (Figure 3C). The region depicting the LA was selected by exploiting LA shape and position knowledge.

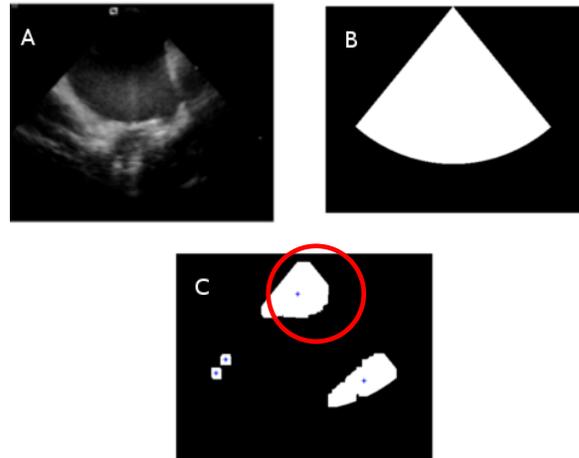


Figure 3. Automated LA centroid detection procedure. A) Original image. B) Mask of the circular sector computed to limit working area. C) Regions detected by applying thresholding segmentation. Red circle indicates the LA region selected by exploiting anatomical information regarding its position.

In this type of acquisition, the LA is typically positioned in the up-right quarter of the echo scan. The centroid of the selected region was then computed (Figure 3C).

## 2.3. LAPW detection: Chan-Vese based method

To detect LA boundaries in images affected by little noise, a procedure based on the region-based level-set Chan-Vese method (CV) was developed.

The region-based level-set Chan-Vese method consists in defining a curve, representing a zero level of a 3D function, in the 2D image space, and letting it evolve by maximizing the differences between the mean gray level values of the two regions, inside and outside the curve.

The method was applied considering the boundary of the region obtained at the previous step (see 2.2) as initial condition. Resulting boundaries are shown in Figure 4.

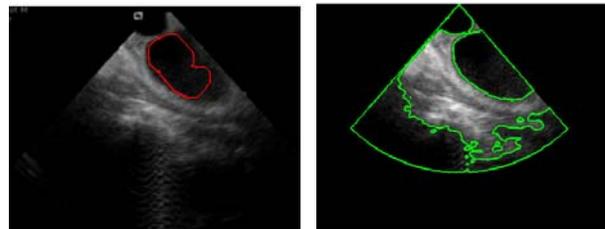


Figure 4. Initial condition (left panel) and final result (right panel) obtained by applying the CV method.

The LA region was selected by using the centroid position previously detected. The segmented area was

refined by applying an opening step allowing the removal of “holes” inside the region. To avoid connection of the atrium with other structures within the resulting mask, an erosion and dilatation step was applied with structural elements of the same size.

An example of the resulting mask is shown in Figure 5.

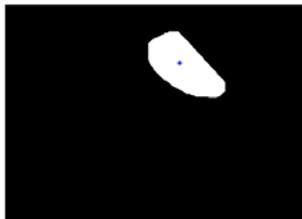


Figure 5. Resulting LA segmentation obtained by applying the CV method and opening operation.

A final correction was necessary to prevent spurious bulges inclusion in the LA cavity (Figure 6). These are approximately circular bulges that extend from the atrium region. So, bulge deletion was achieved by computing the difference between the LA chamber obtained in the considered frame, and the LA chamber obtained in the previous frame, and by subtracting only the regions whose eccentricity is higher than a fixed value experimentally defined.

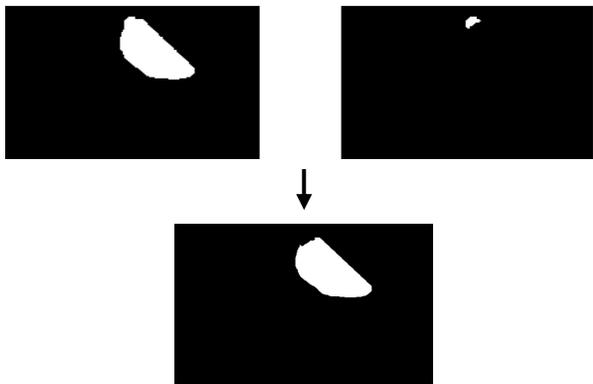


Figure 6. Example of the procedure steps required for bulge deletion. Top left panel: Detected LA cavity including a bulge; top right panel: result of difference between the two LA cavities; bottom panel: final LA cavity obtained eliminating the bulge region from the current LA chamber.

Finally, the detected LA region was refined applying a boundary regularization procedure (see 2.5).

## 2.4. LAPW detection: clustering based method

To detect LA boundaries in very noisy images a procedure based on clustering K-means algorithm was

developed.

The K-means clustering algorithm allows the partition of  $N$  observations into  $k$  cluster, in which each observation belongs to the “nearest” cluster. The number  $k$  of the clusters is a priori defined.

We hypothesized to differentiate pixels corresponding to blood, cardiac structures and noisy regions by applying a clustering K-means method with  $k=3$ . Pixels belonging to the cluster with higher mean gray level value were considered “cardiac structures”; pixels belonging to the cluster with the lower mean gray level value were considered “blood” and the remaining pixels belonging to noisy regions (Figure 7).

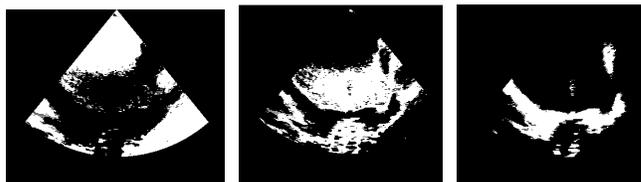


Figure 7. Examples of pixel clustering obtained applying a K-means method with  $k=3$ . On the left panel we show “blood” regions, in the middle panel noisy regions and on the right panel pixels belonging to cardiac structures.

The image was then segmented applying a threshold defined as a weighted average of cluster centers. The resulting detection was refined using morphological operators. In particular, an opening was first applied to remove “holes” inside the regions followed by an erosion, to avoid connection of the atrium with other structures. The region containing the atrium centroid was selected and dilated with a structural element of the same size of the one used for the erosion.

Finally, the detected LA cavity was refined by applying a boundary regularization procedure (see 2.5).

## 2.5. LA boundary regularization procedure

LA contours obtained from the above described procedure were smoothed by applying a regularization step. This was implemented to avoid LA contour introflexion inside the cavity, caused by the presence of noise and artifacts.

The technique consisted in calculating the convex area mask surrounding the LA cavity, and evaluating the gray level intensities of regions included within the convex mask and not included in the LA cavity. In case of “dark” regions, we included those as part of LA cavity.

## 3. Results

Nine ICE sequences were successfully analyzed (7 applying the CV based method and 2 applying the CL

based technique) for a total of 2048 frames. Frame number and size of each acquisition from patient characteristics.

Time required for automated analysis on a personal computer was 0.6 and 1.5 sec/frame for CL and CV, respectively.

An example of the LA border detection obtained applying the two developed methods is shown in Figure 8.

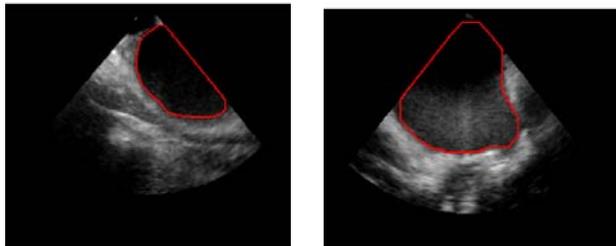


Figure 9. Examples of LA boundaries detection obtained with CV (left panel) and CL method (right panel) respectively.

A success rate was defined considering the number of correct LAPW boundary detection by visual evaluation. LA boundaries were correctly detected in 83,82% and 83,91% of the analyzed frames for CL and CV, respectively.

An example of the comparison between the detected LA contours (in red) and the manually traced LA boundaries by an experienced cardiologist (in green) is shown in Figure 9.

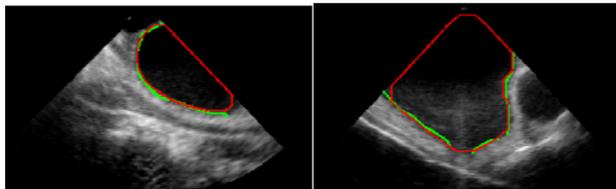


Figure 8. Comparison between manually traced (green) and automatically detected (red) LA boundaries by applying the CV (left panel) and CL (right panel) method.

Quantitative evaluation of the developed procedure was performed by comparing two series of LA boundaries, obtained respectively from CV and CL method, with manually traced LA boundaries by an experienced cardiologist.

Comparison included linear regression and Bland-Altman analysis between LA areas obtained by summing the number of pixels included in the detected contours, as well as Dice coefficient (D) and Hausdorff distance (HD) between LA contours. Results are reported in table 1 and in table 2.

Table 1. Values of the computed similarity indexes for both methods.

	D (mean±SD)	HD (pixels)
CL	0.95±0.029	4.5±0.7
CV	0.94±0.018	4.0±0.6

Table 2. Results obtained by applying linear regression and Bland-Altman to LA area values.

	Linear regression	Correlation coefficient	Bias (pixels (%))	SD (pixels)
CL	y=1.0x-1654	0.92	-1159 (0.73)	1011
CV	y=0.9x-153	0.99	-827 (0.57)	376

#### 4. Discussion and conclusion

Despite the suboptimal quality of the ICE images, the proposed algorithm was able to detect LAPW borders accurately and reliably. Importantly the developed procedure for real-time dynamic detection of LA cavity and LAPW is completely automated.

Further validation on a large number of ICE datasets is necessary, hopefully including data in DICOM format.

These preliminary results are promising and may represent the preliminary step for additional analysis including dynamic quantification of esophagus real-time position' changes and its distance from the LAPW to prevent esophagus injuries.

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