DOI:
10.1007/978-3-319-52718-5_21

Document Version
Peer reviewed version

Segmentation Challenge on the Quantification of Left Atrial Wall Thickness

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Abstract. This paper presents an image database for the Left Atrial Wall Thickness Quantification challenge at the MICCAI STACOM 2016 workshop along with some preliminary results. The image database consists of both CT ($n = 10$) and MRI ($n = 10$) datasets. Expert delineations from two observers were obtained for each image in the CT set and a single-observer segmentation was obtained for each image in the MRI set included in this study. Computer algorithms for segmentation of wall thickness from three research groups contributed to this challenge. The algorithms were evaluated on the basis of wall thickness measurements obtained from the segmentation masks.

Keywords: Image segmentation, Left atrium, CT, Angiography, MRI, Image quantification

1 Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia causing chaotic contraction of the atrium. AF becomes more prevalent with age [1], is frequently associated with atrial remodelling and fibrosis, and causes loss of atrial muscle mass, the severity of which reflects the duration of preexisting AF. Pulmonary vein isolation is often the first procedure performed in patients referred for catheter ablation of AF. The left atrium (LA) is known to undergo changes in structural and electrical behaviour with conditions that predispose AF [2]. Until recently, structural and electrical remodelling in the LA was not very well understood. Success of AF is now highly dependent upon the ability to create fully extent or *transmural* lesions within the LA wall.

The LA wall is a thin structure. Assessment of the LA has been restricted because of its size and blood flow. Measurement of the size of its wall has not been possible *in-vivo* until recently. At first, echocardiography was the only widely available tool for cardiac structural assessment, but it was not well suited because of its low spatial resolution. Transesophageal Echocardiography (TEE) provided higher spatial resolution and has been used to measure increases in wall thickness [3]. The availability of high-resolution imaging technology in CT and Cardiac Magnetic Resonance (CMR) has provided an accurate means of measuring its thickness. State-of-the-art image processing algorithms are also now becoming readily available as open source.

Due to the challenging nature of the problem of wall thickness segmentation and quantification, the Left Atrial Wall Thickness Quantification challenge was put forward publicly and three image processing research groups participated. This work aims to present some preliminary results.

2 Methods

2.1 Imaging data

The image database consisted of CT ($n = 10$) and MRI ($n = 10$) datasets from separate groups of patients. The images were all obtained from a single centre. The CT datasets were obtained from coronary CT angiography scans, with an intravenous contrast agent injection. The scans were ECG-gated and acquired in a single breath hold. The images were reconstructed to a 0.8 to 1 mm slice thickness, with a 0.4 mm slice increment and a 250 mm field of view. The image matrix was kept at a 512×512 matrix, constructed with a sharp reconstruction kernel.

The MRI datasets were acquired with respiratory gating using a pencil-beam navigator and the average scan time was about 12 min. Cardiac triggering ensured that data acquisition was carried out in mid atrial diastole. Table 1 specifies the imaging acquisition parameters. Some example images from this database can be seen in Figure 1.

Table 1. Image acquisition

	CT	**MRI**
Scanner type	Philips Achieva 256 iCT	Philips 3T Achieva
Sequence	Angiography with ECG-gated and single breath hold	3D FLASH, respiratory gating and acquired at mid atrial diastole
TE, TR, TI	-	2.7 ms, 5.9 ms, $450 - 700$ ms
Voxel in-plane	0.8 to 1 mm	1.4 mm
Slice thickness	0.4 mm	1.4 mm

Image acquisition parameters for the challenge CT and MRI data. Abbreviations: TE - Echo time, TR - Repetition time, TI - Inversion time

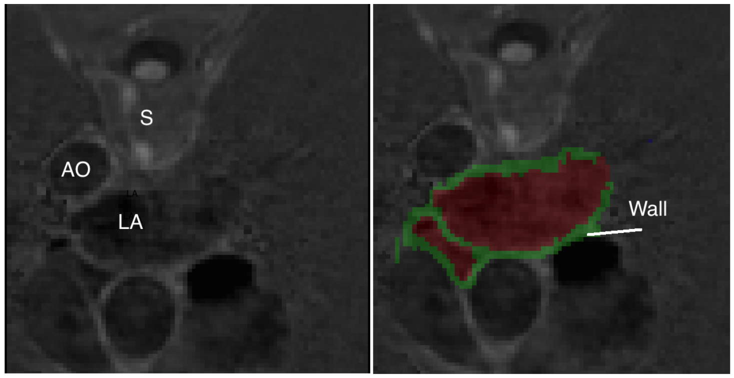


Fig. 1. MRI database: Example image from the image database (left) and its expert delineation of wall and blood pool chamber. Abbreviations: LA - left atrium, AO - Aorta, S - spine.

2.2 Atrial wall delineation

The atrial wall, in CT, was semi-automatically delineated by two observers with expertise on left atrial imaging. In the MRI datasets, these were manually delineated silce-by-slice by a single observer with good experience on atrial scans. The semi-automatic process on CT images consisted of a pixel-by-pixel dilation initiated from the atrial blood pool chamber. A single pixel dilation was compulsory followed by subsequent conditional dilations. These conditional dilations depended on a patient-specific atrial wall intensity range and thickness. This was followed by manual editing of the wall in each separate section of the image.

2.3 Evaluation of wall thickness

To study the performance of the algorithms submitted for the segmentation challenge, the binary segmentation masks obtained from each algorithm were analysed for left atrial wall thickness (LAWT). The thickness on the anterior and posterior sections of the LA were evaluated separately. In order to obtain LAWT from the binary masks an isotropic dilation process was implemented.

Determining LAWT from binary masks of the wall is not straightforward. Projecting and traversing normals from the inner boundary of the wall to its outer boundary to measure thickness has one important limitation. In regions of high curvature, the normals can be noisy resulting in misestimation of thickness. In [4], the authors highlighted these limitations and derived thickness from the length of field lines. These field lines were obtained from the Laplace solution that spanned the wall from the inner to the outer wall. In this work, a similar approach was undertaken by deriving such field lines using iterative isotropic dilation.

Dilation was initiated from the endocardial mask and dilated by a single pixel in each direction, with up to ten iterative steps covering the entire possible

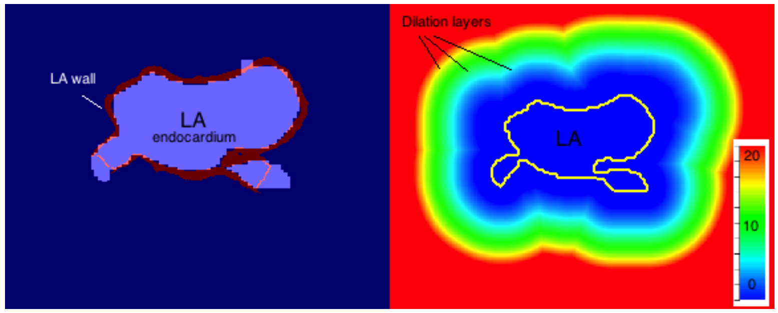


Fig. 2. This figure illustrates how the wall thickness is measured from binary masks of LA endocardium and wall segmentation (left). Iterative dilation of ten steps of the endocardial mask determines distance from each dilation layer (right).

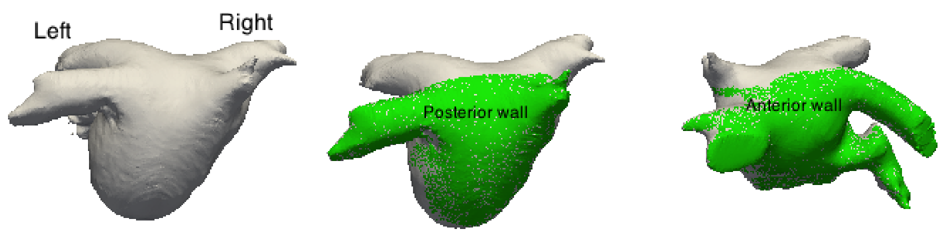


Fig. 3. The wall thickness was evaluated on the posterior and anterior sections of the wall. The image highlights these sections in the LA anatomy.

width of the wall. Each *layer* of dilation of the endocardial mask determined the distance from the endocardium. Thus, the LAWT at all points on the LA wall masks could be measured by correspondence with the dilated layers of the endocardium. These steps are illustrated in Fig. 2.

2.4 Sectional analysis of the wall

The LAWT measured by each algorithm was evaluated on the posterior and anterior sections of the wall. The LA in each image was subdivided into these sections. The LAWT statistics in these sections were computed and compared between algorithms. Sectional analysis of the wall is relevant as several tissue based studies have highlighted regional differences in atrial wall thickness, even within superior and inferior aspects of the wall [5]. Different conclusions have been cited regarding comparative tissue thickness [6, 7]. Fig. 3 illustrates with an example how the wall was subdivided in this study.

3 Results

Three research groups contributed to this challenge. These were INRIA Asclepios in France (INRA), Robarts Institute in Canada (ROBI) and Leiden University Medical Centre in The Netherlands (LUMC). INRA used region-growing to obtain the LA endocardium, followed by geodesic active contours for the LA epicardium. ROBI used intensity based thresholding by determining the threshold between ventricular myocardium and surrounding tissue. This was set at two standard deviations from the mean of myocardium intensity in Hounsfield units (HU). LUMC employed a multi-atlas registration of ten atlases for locating the LA chamber and pulmonary veins. A level-set evolution initiated from the LA chamber segmented the atrial wall based on the HU and incorporating prior knowledge of wall thickness.

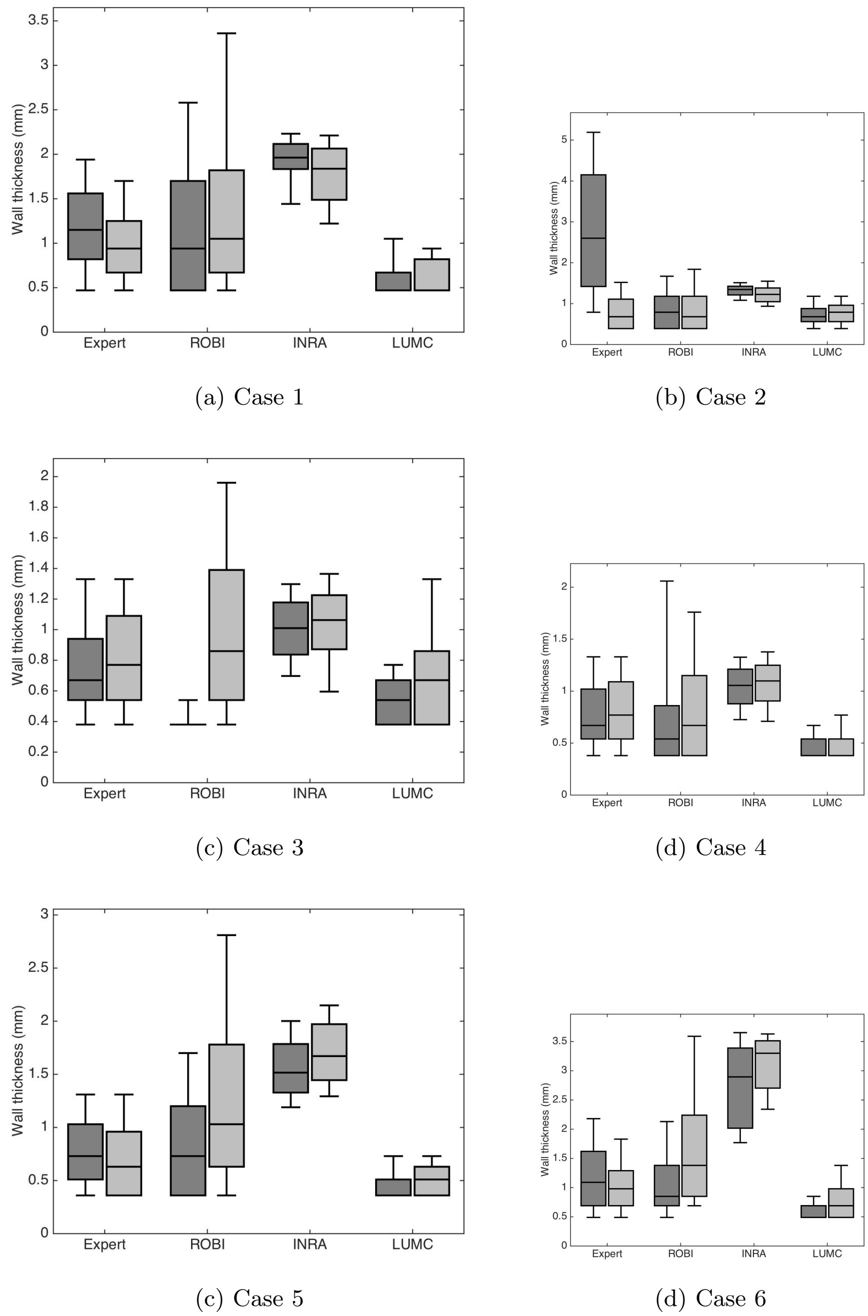
The algorithms were evaluated and compared by computing the LAWT from their outputs. The expert delineations were also compared. The LAWT of the posterior wall computed on the CT images were (Mean $\pm$ SD): 1.1 ± 0.9 mm, 1.0 ± 0.7 mm, 1.6 ± 0.7 mm, 0.6 ± 0.2 mm for expert delineations, ROBI, INRA and LUMC respectively. For the anterior wall, the LAWT were (Mean $\pm$ SD): 0.9 ± 0.4 mm, 1.3 ± 0.9 mm, 1.7 ± 0.8 mm, 0.7 ± 0.3 mm for expert delineations, algorithms ROBI, INRA and LUMC respectively. Fig. 4 provides a comparison in six separate cases. A sample segmentation from each algorithm is shown in Fig. 5.

The participating research groups did not choose to segment images from the MRI database. The expert delineations of the wall were evaluated by computing LAWT in five random images. The LAWT of the posterior wall computed on the MRI for the five separate images were (Mean $\pm$ SD): 2.1 ± 0.7 mm, 1.9 ± 0.7 mm, 1.8 ± 0.6 mm, 1.9 ± 0.8 mm, 1.9 ± 0.7 mm. The LAWT of the anterior wall computed in the five separate images were (Mean $\pm$ SD): 1.9 ± 0.7 mm, 1.5 ± 0.6 mm, 1.7 ± 0.7 mm, 1.6 ± 0.7 mm, 1.8 ± 0.9 mm. The comparison of LAWT in the five cases is shown in Fig. 6.

4 Discussions

There is good agreement between the algorithms and expert delineations on the posterior wall. The exception is LUMC which under-estimates the thickness in most cases. However, there is good agreement between LUMC and the expert delineation on the anterior wall. Both ROBI and INRA report greater thickness for the anterior wall. The posterior wall is found to be generally thicker than the anterior wall in the CT scans. This has also been reported in some meta studies [8]. Some algorithms have imposed a minimum thickness constraint, usually one pixel (i.e. 0.4 mm), resulting in the slightly skewed box-plots.

The range of LAWT values measured with MRI was in close agreement with CT, both for the posterior and anterior walls. The MRI and CT images were not from the same patients. For a more extensive analysis of LAWT in MRI, refer to [9].



(a) Case 1 (b) Case 2

(c) Case 3 (d) Case 4

(c) Case 5 (d) Case 6

Fig. 4. Sectional wall thickness analysis of the submitted algorithms in six randomly selected CT images from the database. In each sub-plot, the bars to the left and right represent posterior and anterior walls respectively.

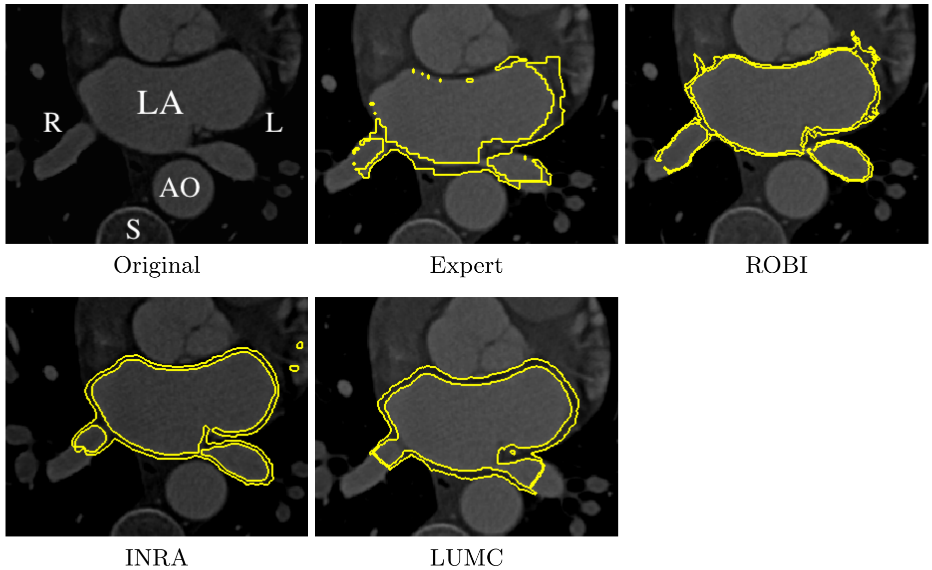


Fig. 5. One example from the CT database comparing segmentations of the atrial wall in the expert delineation and the submitted algorithms. Abbreviations: L - left side, R - right side, LA - left atrium, AO - Aorta, S - spine.

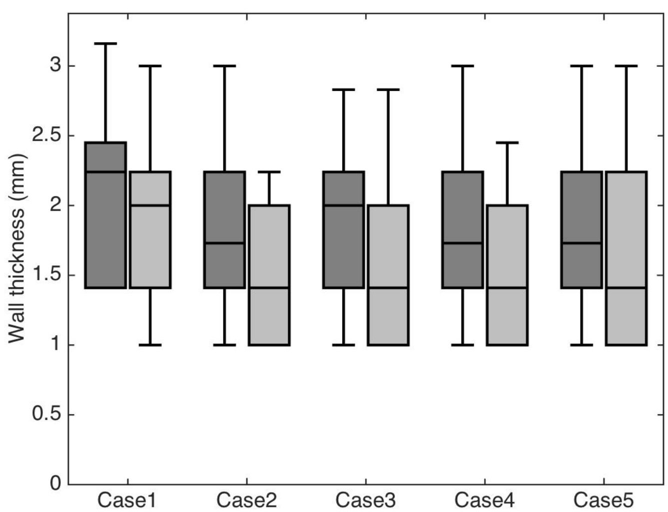


Fig. 6. Wall thickness in expert delineations of five randomly selected MRI images from the challenge image database

5 Conclusions

This work collates results of the algorithms on the image database released for quantification of atrial wall thickness. To our knowledge, this database is the first of its kind for left atrial wall. Future work will provide an extensive analysis of the algorithm results.

Acknowledgements: This research was supported by the National Institute for Health Research (NIHR) Biomedical Research Centre at Guy's and St Thomas' NHS Foundation Trust and King's College London. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

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