3D left atrial appendage modelling: a multimodal imaging approach

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***Abstract*—The left atrial appendage (LAA) is a complex structure responsible for 90% of thrombus formation in patients with non-valvular atrial fibrillation. Our aim was to evaluate the feasibility of creating dynamic 3D LAA models from CT and US images, to be used in assessing of LAA anatomy and function and in assisting pre-operative planning. 3D LAA surface models were created for each cardiac phase; a custom plug-in software was developed to extract LAA anatomical and functional parameters directly from the 3D models. LAA parameters obtained by CT models were validated through comparison with the ones obtained using the gold standard technique, and a strong agreement between the two methods was found. LAA assessment by 3D models based method is feasible and 3D LAA surface models can be printed to support the preoperative evaluation or used for virtual procedure simulations and biomechanical characterization by finite element software.**

***Keywords*—left atrial appendage, 3D model, CT, 3D echo.**

I. Introduction

THE left atrial appendage (LAA) is a site responsible for 90% of thrombus formation in patients with non-valvular atrial fibrillation (NVAF) [1]. In case of NVAF and contraindications to anticoagulation therapy, the percutaneous LAA closure is a treatment strategy to reduce the cardioembolic risk. This procedure is particularly difficult because of LAA anatomical complexity. Previous studies investigated the LAA anatomy and function and their possible role in thrombus formation using different imaging modalities [2]-[4].

Our aim was to assess the feasibility of creating 3D STL (Stereo Lithography interface format) dynamic LAA models from CT and US images to extract LAA parameters and to improve the preoperative planning by 3D printing support.

II. Methods

Two different imaging modalities were used for the volumetric LAA acquisition: ECG-gated cardiac CT and 3D intracardiac echocardiography (ICE). The gated CT acquisition was characterised by 10 phases. In order to synchronise the 4D US acquisition with the 4D CT dataset, the ICE image sequences were sub-sampled at 10 phases.

Two software were used for LAA segmentation and 3D surface models creation (3Mensio for CT images, 3DSlicer for ICE images). For each phase of the cardiac cycle, the corresponding 3D STL model was created. A custom plug-in software was developed in Matlab to measure LAA volume and LAA ostium area directly from the 3D surface models. LAA ejection fraction (LAAEF) was calculated to assess the LAA motility. The 3D models based method for LAA parameters extraction was validated on 10 CT dataset from patients scheduled for percutaneous LAA closure procedure. For the validation, LAA ostium area and LAA volume in the LA systolic and diastolic phases were measured availing the Simpson's method, the gold standard technique [5], by using Osirix software. The intra-observer reproducibility was assessed by Coefficient of Variation (CoV), both for 3D models based method and for gold standard technique. Agreement between methods was assessed by paired t-test.

A 3D LAA model from CT was printed to simulate the LAA closure procedure.

III. Results

Generating 3D LAA models was feasible by using both CT and 3D ICE images, as shown in Fig.1. The higher anatomical accuracy of CT models made these more reliable for the 3D printing.

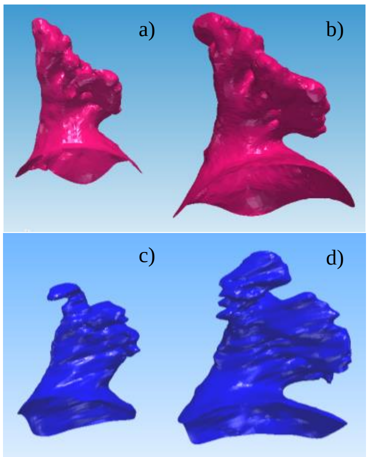

Fig.1 – LAA 3D surface models at the LA systolic and diastolic phases, from cardiac CT images (a, b) and from 3D ICE images (c, d).

Fig. 2 shows an example of LAA volume variation curves during the cardiac cycle, obtained by CT and US data. CT images analysis with the gold standard technique has validated the results given by our method, proving that the extraction of LAA reliable measurements directly from 3D LAA models is feasible. Validation results were summarised in Table I; the method we proposed had a better intra-observer reproducibility and a strong agreement with the gold standard technique. The availability of a 3D LAA model for each phase of cardiac cycle allowed the LAA motility evaluation. The LAAEF values obtained in this study were

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TABLE I
VALIDATION RESULTS

LAA parameters	*3D models based method*	*Gold Standard method*	*3D models based method – BSA normalized*	*Gold Standard method – BSA normalized*	*3D models based method - CoV*	*Gold Standard method - CoV*	*p-value*
Ostium Area$_{max}$	4.80 ± 1.66 cm^2	4.77 ± 1.53 cm^2	2.78 ± 1.16 cm^2	2.76 ± 1.08 cm^2	2.6%	4.1%	0.5045
Ostium Area$_{min}$	3.78 ± 1.72 cm^2	3.79 ± 1.69 cm^2	2.19 ± 1.13 cm^2	2.20 ± 1.09 cm^2	3.7 %	6.1%	0.8227
Volume$_{max}$	10.61 ± 5.17 cm^3	10.55 ± 4.88 cm^3	6.19 ± 3.67 cm^3	6.19 ± 3.63 cm^3	2.5%	5.2%	0.8319
Volume$_{min}$	7.51 ± 4.85 cm^3	7.46 ± 4.71 cm^3	4.39 ± 3.28 cm^3	4.38 ± 3.27 cm^3	2.6%	5.9%	0.7693
LAA EF	33 ± 16 %	33 ± 16 %	33 ± 16 %	33 ±16 %	6.2%	17.1%	0.9993

Ostium Area$_{max}$: LAA ostium area during the LA diastolic phase; Ostium Area$_{min}$: LAA ostium area during the LA systolic phase; Volume$_{max}$: LAA volume during the LA diastolic phase; Volume$_{min}$: LAA volume during the LA systolic phase; LAA EF: LAA ejection fraction; CoV: Coefficient of Variation to evaluate the intra-observer variability; p: p-value from paired t-test for the agreement between our method (3d models based) and the gold standard one.

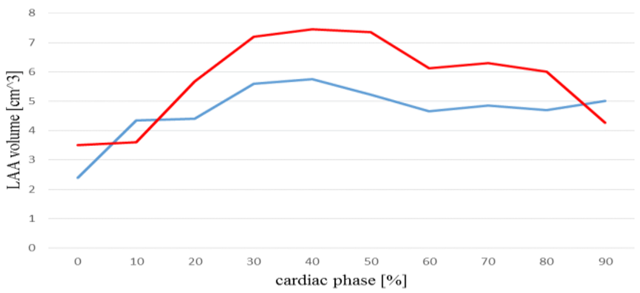

Fig.2 - LAA volume variation curve during a full cardiac cycle, obtained by 3D LAA models from CT (red) and US (blue) images.

compared to the ones concerning normal patients without NVAF or cardiovascular diseases reported in a previous work (55±17 %) [6]. The comparison has validated the hypothesis of the reduction of LAA contractile function in NVAF patients, hence reduced LAAEF could be considered as a risk factor in thrombus formation.

IV. CONCLUSION

The comparison with the gold standard technique has validated the 3D models based method we proposed, which proved to be able to measure LAA anatomical and functional parameters reliably. Generating 3D LAA models covering the entire cardiac cycle was feasible by using both CT and US images. The capability of working with different images sources plays an important role in the field of the interventional cardiology due to the possibility of fusing reconstructed 3D models with 2D angiographic images (Fig. 3a). Moreover, our multimodal approach allowed evaluating limits and advantages of the two imaging modalities. Although 3D echocardiography has the benefit of a greater time resolution, CT models are more suitable for 3D printing because of their greater anatomical accuracy. A 3D LAA model from CT was printed to simulate the LAA closure procedure (Fig. 3b) and it provided a tangible and accurate LAA reproduction, which assisted the choosing of the size and the position of the occluder device. Currently, simulation practice avails the 3D printing support, but future works will include the use of 3D LAA models for virtual simulation of LAA closure procedure by finite element (FE) software. FE simulations will be able to evaluate the wall overstretch in the case oversizing of the device (Fig. 3c). The possibility of using 3D LAA models from both CT and US images for the future FE simulations is useful considering that the choice of the best modality for the LAA imaging is still an open topic. Finally, the difficulty of having available LAA histological data suggests the LAA biomechanical characterization by reverse engineering technique as a further future application of 3D LAA models.

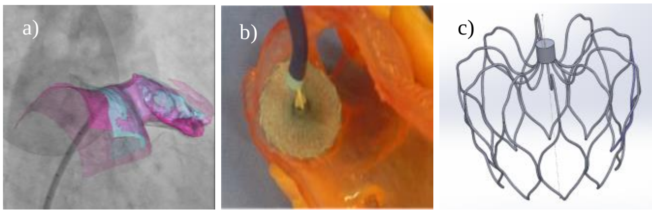

Fig.3 – Example of XA-CT-ECHO image fusion (a); LAA closure procedure simulation by 3D printing support (b); 3D CAD model for LAA closure by means of finite element simulation (c).

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