A Novel Framework for Unified Analysis of In-vivo and Ex-vivo Cardiac Data Using an In-vivo MRI-derived 3D Printed Model: Application to Cardiac MRI

Sébastien Roujol[1], Cory Tschabrunn[1], Tamer A. Basha[1], Kraig V. Kissinger[1], Warren J. Manning[1,2], Mark E. Josephson[1], Elad Anter[1], and Reza Nezafat[1]

[1]*Department of Medicine, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, Massachusetts, United States,* [2]*Department of Radiology, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, Massachusetts, United States*

Target Audience

Scientists and clinicians who are interested in in-vivo and ex-vivo cardiac MRI.

Purpose/Introduction

A variety of animal models have been used in cardiac MRI (CMR) studies to help characterize the underlying mechanisms of several cardiomyopathies[1]. In-vivo and ex-vivo CMR often provide complementary information. In-vivo CMR can be used for hemodynamic, functional and viability evaluation while ex-vivo CMR can provide structural information with high resolution due to the absence of physiological motion. The combination of these information is however challenging since the excised heart generally shows substantial variations in shape, when compared to the same in-vivo heart. In this study, we sought to investigate the feasibility of integrating a 3D printed model of the in-vivo LV cavity into the ex-vivo heart to enable imaging of similar LV shape during in-vivo and ex-vivo CMR.

Materials and Methods

Creation of a 3D printable mesh of the LV cavity:

Figure 1 illustrates the proposed workflow for the creation and integration of a 3D printed model of the in-vivo LV in an excised heart. In-vivo CMR is first performed to obtain a high resolution 3D volume of the entire LV. The endocardial contour is then manually delineated over the entire LV (red contour in Figure 1a). An inner contour is automatically generated by projection of the endocardial contour in the radial direction of the heart (blue contour in Figure 1a) to enable the creation of a closed loop surface. No inner contour is generated in the most apical slice. Endocardial and inner meshes are then individually created and closed in their most apical layer. A combined mesh is created by merging both meshes at their most basal layer. Face normals are generated to indicate the inside/outside area to be considered for 3D printing. The resulting mesh is finally exported in the STereoLithography (STL) format. All these steps were implemented in Matlab. Finally, a smoothing operator is applied to the mesh using the MeshLab software (Visual Computing Lab - ISTI - CNR).

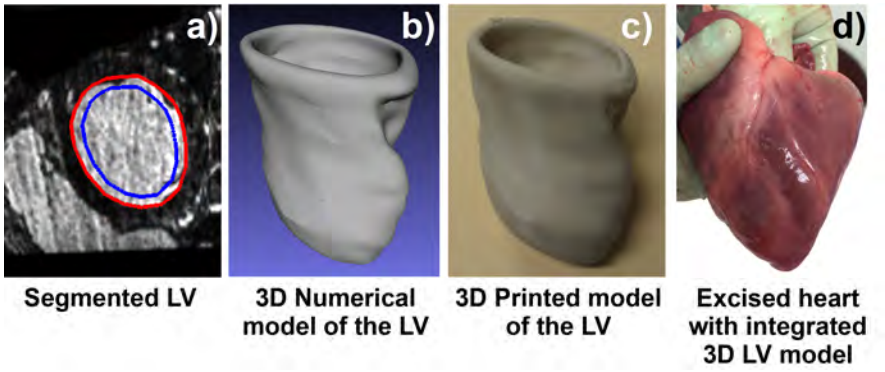

Figure 1. *Proposed workflow for integration of an in-vivo LV MR-derived 3D printed model in an excised ex-vivo heart. a) endocardial contour is manually delineated (red) and an inner contour (blue) is automatically generated; b) numerical LV model; c) 3D printed LV model; d) integration of 3D printed model and excised ex-vivo heart.*

Insertion of the 3D LV printed model in the excised heart: Following the experimental procedure the heart is excised and a 4.0cm vertical incision along the posterior left atrium extending across the mitral valve annulus into the left ventricle is made to facilitate insertion of the 3D printed model. A posterior approach was chosen to avoid disruption of tissue regions of interest.

Experimental validation: Application to high resolution scar imaging in swine model of ventricular tachycardia

All CMR imaging was performed on a 1.5 T Phillips scanner. A swine model of ventricular tachycardia was created in one Yorkshire swine by 180 min balloon occlusion of the mid left anterior coronary artery. In-vivo imaging was performed at 40 days after infarction. High resolution LGE[2] was performed using a free breathing navigator-gated inversion recovery gradient echo sequence (TR/TE/α=6.5/3.0ms/25˚, FOV=270×270×112 mm^3, voxel size=1×1×1 mm^3, compressed sensing factor=4) and was reconstructed using compressed sensing[3]. A 3D model of the LV chamber cavity was then created from this scan and was 3D printed with a 200 micron resolution using a Replicator 2 printer (MakerBot Industries, LLC) at an outside commercial vendor for a cost of $30. Four days later, the animal received an injection of 0.2 mmol/kg of gadobenate dimeglumine and was euthanized 20 minutes later. The 3D model was then surgically inserted in the excised heart. Ex-vivo CMR followed using a high resolution T_1-weighted acquisition with GRE imaging (voxel size=0.5×0.5×0.5 mm^3, 3 averages). For comparison, in-vivo and ex-vivo images obtained from a second swine which underwent the same protocol without surgical integration of a 3D printed model for ex-vivo CMR are reported.

Results

The overall surgical operation was found straightforward and could be performed in less than 5 minutes. The septal and lateral edges of the model aligned well with the endocardial tissue and insertion was performed without difficulty or disfiguration of the heart. Figure 2 shows example in-vivo LGE and ex-vivo T_1-weighted data acquired without (Swine #1) and with (Swine #2) integration of a 3D printed model prior to ex-vivo CMR. Substantial shape variations were observed between in-vivo and ex-vivo CMR data in all swine where the 3D model was not integrated prior to ex-vivo CMR. Improved visual matching of LV shape was obtained between in-vivo and ex-vivo CMR data obtained in the swine imaged with the implanted 3D printed model. Furthermore, the 3D model did not generate any imaging artifacts.

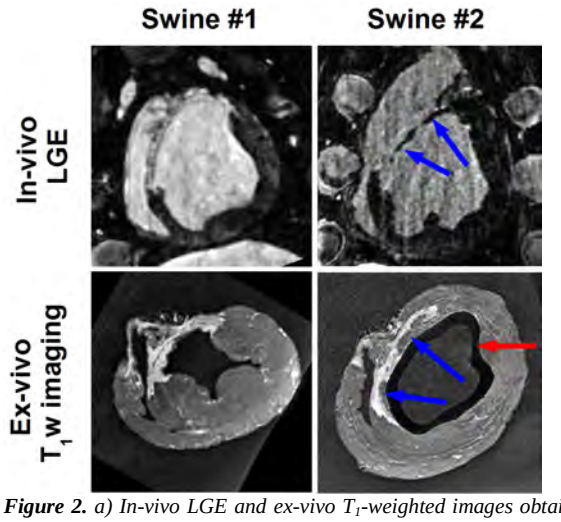

Figure 2. *a) In-vivo LGE and ex-vivo T_1-weighted images obtained in a swine which did not underwent 3D model integration (a) and a swine who underwent 3D model integration (b). The proposed platform substantially improves the similarity of in-vivo and ex-vivo measurements.*

Conclusions

The creation of an MR-compatible 3D printed model of the in-vivo LV chamber cavity is feasible. The model can be readily inserted in an excised heart and greatly improves the correspondence of in-vivo and ex-vivo CMR data. Finally, this platform offers promising perspectives for multimodal integration of various information such as electrophysiology and pathophysiology information, as well as for CMR studies involving heart transplant.

Acknowledgements

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References

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