Generation of a simulation scenario from medical data: Carto and MRI

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Abstract- *Multiphysic cardiac models give accurate simulations of normal and pathologic behavior of the heart. It can help to develop new treatments and medical devices. The complexity relies on both mathematical and geometrical models, so that HPC is needed to obtain accurate results using finite element method. From Magnetic Resonance Imaging a complete geometry, including atria and ventricles, is obtained through segmentation. Then the corresponding CAD is generated, where boundary conditions and properties of each heart region are fixed. Finally the volume mesh is built, essential to run simulations.*

A. Introduction

Cardiovascular diseases are the main causes of death in the world. It is important to find new pharmacology treatments and devices. On this field, simulations can help to understand the behaviour of normal and pathologic hearts. Different kind of problems are necessary to face when solving fluid-electromechanical cardiac simulations: geometry and mesh generation, fiber orientation, scar definition, model parameterization and boundary conditions. In this work, we focus on geometry, mesh generation and electrical characterization from the experimental medical data.

When speaking about cardiac infarction is important to differentiate the scar zones. Each zone has different electrical and mechanical properties that have to be included on the final mesh.

The final goal is to obtain a complete volume mesh with all the medical information included and able to run electromechanical cardiac simulations on it.

B. MRI-Based Geometry

Most electrophysiology simulations use simplified geometries based on ellipsoids. This is not enough once we introduce the mechanical problem. A complete heart geometry is needed, that is including atria and ventricles. This geometry is obtained from the Magnetic Resonance Imaging (MRI) through segmentation.

The MRI images are first filtered and then manually segmented using the software *Amira* [3]. Once the geometry contours of atria and ventricles are defined, the corresponding CAD is generated. The CAD is useful to fix boundary conditions and the properties of each heart region and finally create the first volume mesh (Figure 1).

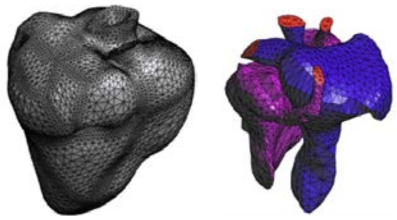

Fig. 1. Complete heart mesh (left) and cavities mesh (right).

When studying myocardial infarction and ventricular tachycardia, it is important to detect and differentiate the heterogeneous and the dense scar zones. The R1 sequences with gladolinium contrast are the best images to detect scar. Considering [4], first the maximum intensity pixel value within ventricles has to be detected. Observing the pixel intensity histogram on ventricles area, the maximum value corresponds to this maximal intensity pixel.

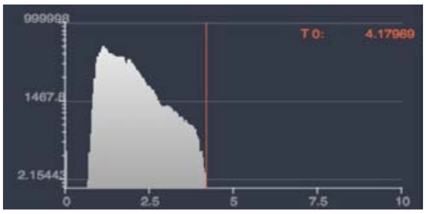

Fig.2: Ventricle pixel intensity histogram. Maximum value: 4.17969

The images are then filtered and the signal intensity normalized to that maximum signal intensity value found. Finally, the regions are classified by thresholds: Dense scar region (0.8 – 1) and heterogeneous region (0.5 - 0.8).

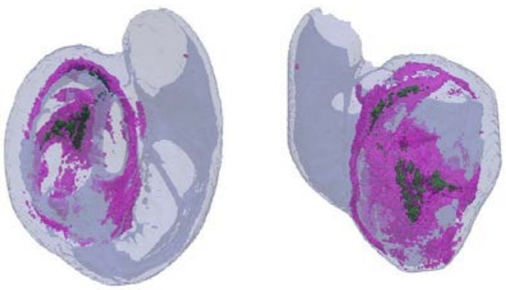

Fig. 3: Reconstruction of ventricles with heterogeneous scar (pink) and dense scar (green).

C. Electrical Properties form Carto

Electromechanical models have to be calibrated with experimental data. Carto data are obtained through a catheter introduced in the heart cavities and pericardia to record the electrical properties on hundreds points of heart surface. This data gives us information about conductivities, activation and restitution times on the different areas of the heart: healthy tissue, heterogenous scar and dense scar. To include this information on the mesh first it has to be compared with the MRI data, to find correspondences between areas.

The scar information coming from MRI data is 3D geometry and the one coming from Carto is surface information. To compare both data, we propose to solve the Eikonal equation on the 3D geometry reconstructed from an MRI segmentation.

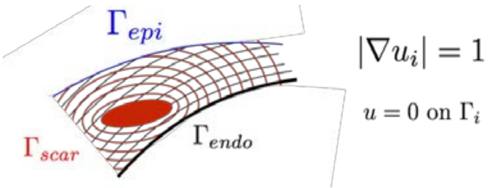

Fig. 4: Scheme of eikonal function applied to ventricles wall and intern scar

If $i =$ *scar*, the values of the Eikonal function on the walls describe the minimum distance to the scar. If $i =$ *endo (*or $i =$ *epi)*, the corresponding values on the epicardium (or endocardium) wall describe the local thickness. Then a normalization of the distance to scar with local wall thickness is applied.

Considering the threshold 0.25 on the normalized surface map, we compare the result scar areas with the Carto data (Figure 4). With this threshold, the 25% of the local ventricle thickness from the epicardium and endocardium are taken into account to measure the distance from the walls to the scar.

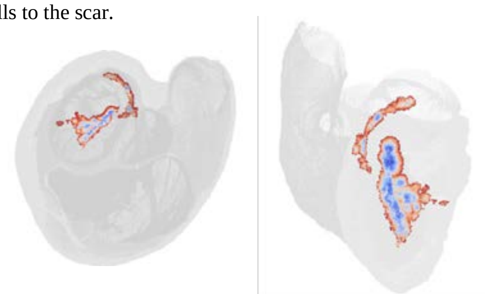

Figure 4: Distance to dense scar surface map normalized by local thickness.

Both methods give similar percentage of dense and heterogeneous scar areas, comparing with the total endocardium and epicardium areas (Figure 5).

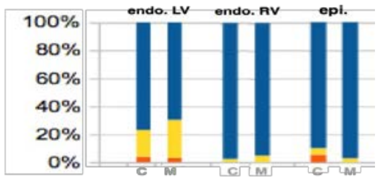

Figure 5: Heart zones areas of Carto data(C) and Mri data (M) in percentages (orange: dense scar, yellow: heter. Scar and blue: healthy zone)

The result relates scar areas taken form different experimental data (MRI and Carto). Now, point-to-point correspondences of data have to be found to get a transformation of Carto surface to MRI geometry. This transformation will be useful to take the electrical data from Carto (conductances and restitution times) of the scar and healthy areas and introduce on the mesh generated from MRI data to parameterized the electromechanical problem.

D. Simulations

The heart mesh obtained form experimental data, including properties of the scar and normal regions, is essential to run our electromechanical model [2]. Cardiac simulations including scar will be run on the multiphysics code Alya, optimized for HPC. The problem combines a mechanical contraction and electrical propagation model that run on the same mesh. Electromechanical simulations are our main objective and the final application of the current work presented.

Acknowledgment

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