Segmentation of the biventricular structure from cardiac MRI images and model meshing

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ADVANCED COMPUTING

Introduction

Heart physiology is a vast and interdisciplinary research subject, on which cardiac modeling plays nowadays a fundamental role. Research groups are focusing their work on studies where experimental data is used to create models which accurately represent the heart functioning and its properties (Figure 1 - left), either for an entire cardiac cycle, or for specific cardiac phases such as end-diastole (ventricular blood filling) and end-systole (ventricular blood ejection).

Myocardial Infarction (MI), a cardiac event that can cause severe alterations in the heart ventricles wall (ventricular remodeling) and one of the dominant causes of death worldwide, is one of the main areas of investigation in cardiac modeling. Regarding this, the development of several computational studies using patient-specific (PS) **biventricular models** remains a top priority.

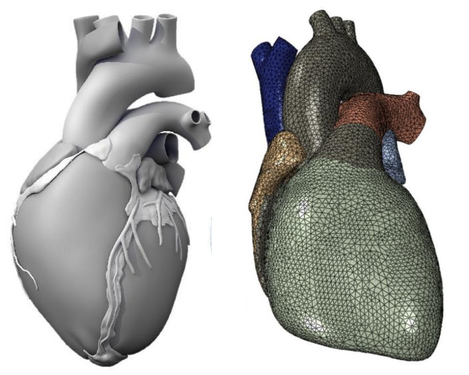

Figure 1: First fully whole heart model (left) and its mesh (right).

Biventricular models are obtained by image-based 3D reconstruction of the biventricular geometry. In this process, segmentation of specific cardiac structures from in vivo imaging modalities such as **magnetic resonance imaging** (MRI) is an important step in the acquisition and creation of cardiac models.

These cardiac models undergo mesh generation (Figure 1 – right), where the geometrical domain is divided into subdomains, with specific governing equations, for an approximated computational analysis.

Work aim: To obtain biventricular geometrical models from pig cardiac MRI, at both end-diastolic and end-systolic phases of the cardiac cycle for posterior computational modelling in myocardial infarction studies.

Methods

The same workflow is adopted for each set of cardiac MRI (Figure 2) and for the generation of each biventricular geometry. Although segmentation of the biventricular geometry was performed, the final models used for meshing were previously obtained by Samarth Raut, in ICES.

simpleware – ScanIP is used for manual segmentation, which allows to delineate the ventricular wall (Figure 3) in order to further build a cardiac model.

→ The resulting biventricular model undergoes smoothing procedures, by the use of ScanIP filters and some manual segmentation repeating.

→ A surface mesh is then created in ScanIP (Figure 4), which is exported into MeshLab , where it is submitted to further smoothing.

→ The smoothed model is imported into Trelis and surface and volume mesh are created: triangular and tetrahedral mesh elements are chosen, because they are better adapted to any 3D volume (Figure 5).

→ Different element sizes are chosen according to the geometry and mesh optimization is performed with element remeshing.

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The number of degrees of freedom is increased in each element node (from 4 to 10) to improve mesh quality.

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Specific groups of mesh nodes are created according to the biventricular structure topology for different properties attribution in sequential computational simulations.

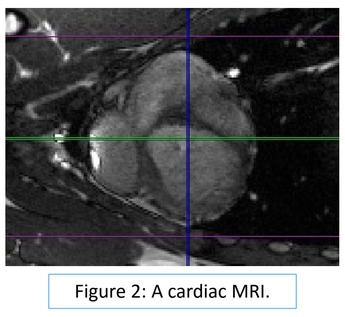

Figure 2: A cardiac MRI.

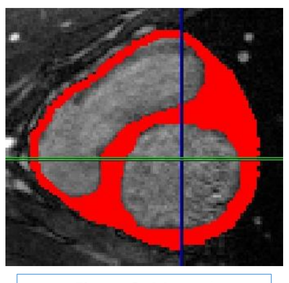

Figure 3: Manual segmentation of the biventricular structure.

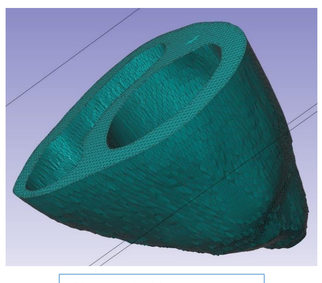

Figure 4: Biventricular model in ScanIP.

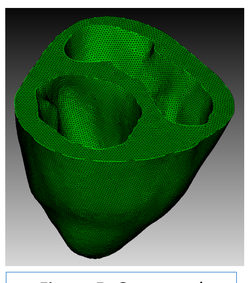

Figure 5: Generated mesh in Trelis.

Results and Discussion

Three geometrical meshes and their respective quality graphical images, are obtained: two differently refined for the end diastolic-phase and one for the end systolic-phase of the cardiac cycle.

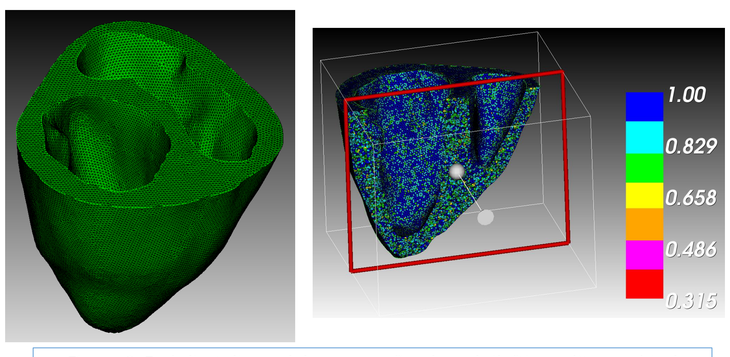

Figure 6: End-diastolic model – more refined mesh (left); quality graphical display (right) – elements in blue are good and elements in red are poor.

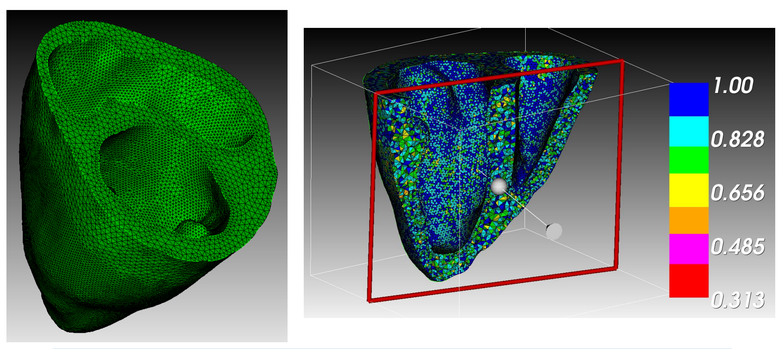

Figure 7: End-diastolic model – less refined mesh (left); quality graphical display (right) – elements in blue are good and elements in red are poor.

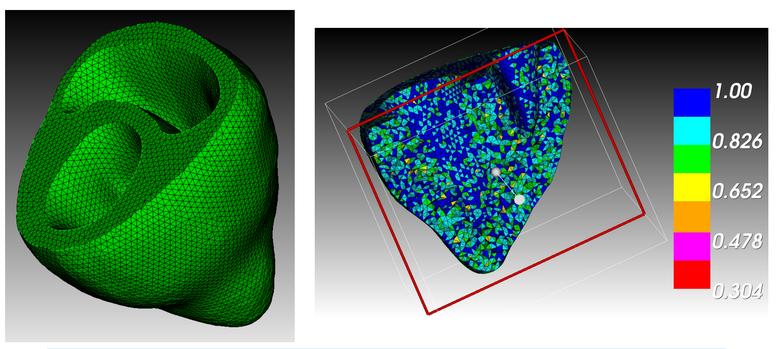

Figure 8: End-diastolic model – more refined mesh (left); quality graphical display (right) – elements in blue are good and elements in red are poor.

The more refined mesh considered for end-diastolic phase (Figure 6) is uniform with elements of approximate size equal to 1. This mesh is too heavy for usual computational simulations and therefore a less refined mesh is used (Figure 7): an adaptive mesh with elements size from 1 to 2. Finally, the end-systolic geometry mesh (Figure 8) is built with an approximate element size equal to 2 and a uniform mesh.

Despite the subjectivity of the segmentation process, the resulting cardiac models are accurate and are a good representation of the biventricular geometry.

The majority of the tetrahedral elements for each mesh seem to have good quality, even though some elements with lower quality appear, especially in the less refined meshes. This is usual in PS models, because the geometry presents irregularities, forcing mesh elements to adapt the best possible.

Conclusions

- The creation of cardiac models for computational studies, not only regarding MI but also related to other cardiovascular conditions, is nowadays crucial. It can help overcoming difficulties related to the information obtained from cardiac imaging techniques, especially regarding health outcomes prediction.
- For the future, research towards automatic segmentation methods which can give rise to accurate models and overcome issues such as the highly variable nature of cardiac anatomy, function and pathology, must be encouraged.

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