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Impact of tissue microstructure on a model of cardiac electromechanics based on MRI data

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Introduction

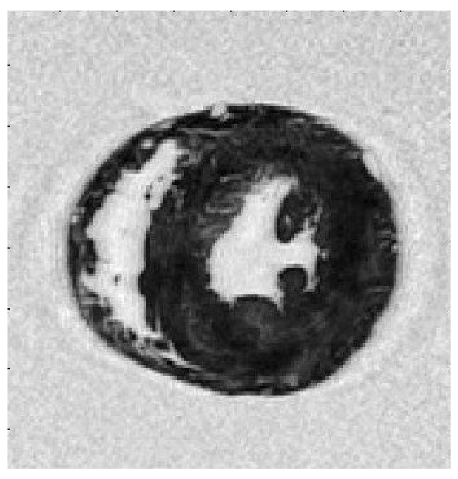
• Cardiac motion is a vital process as it sustains the pumping of blood in the body. For this reason motion abnormalities are often associated with severe cardiac pathologies. Clinical imaging techniques, such as MRI, are powerful in assessing motion abnormalities but their connection with pathology often remains unknown.
• Computational models of cardiac motion, integrating imaging data, would thus be of great help in linking tissue structure (i.e. cells organisation into fibres and sheets) to motion abnormalities and to pathology. Current models, though, are not able yet to correctly predict realistic cardiac motion in the healthy or diseased heart.
• **Our hypothesis is that a more realistic description of tissue structure within an electromechanical model of the heart, with structural information extracted from data rather than mathematically defined, and a more careful definition of tissue material properties, would better represent the high heterogeneity of cardiac tissue, thus improving the predictive power of the model.**

Aim of the study

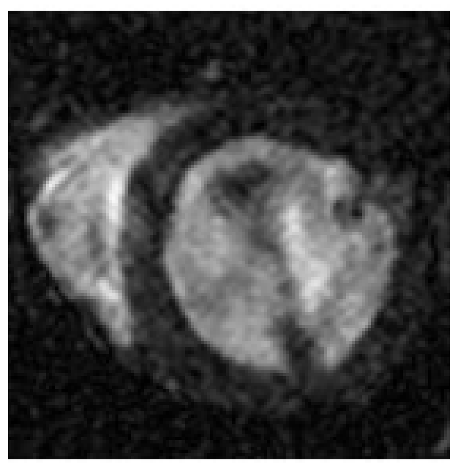
• Investigate how microstructure affects motion prediction of an electromechanical model [1] applied to a rat left ventricular geometry obtained from MRI.
• The questions that will be tackled are :
(a) Which aspects of tissue structure are crucial to obtaining a realistic/accurate motion pattern.
(c) How important is fibre/sheet definition for the active and passive response of the left ventricle.
(d) Which part of the cardiac cycle is more sensitive to tissue structure properties.

Materials and Methods

a. The MRI data



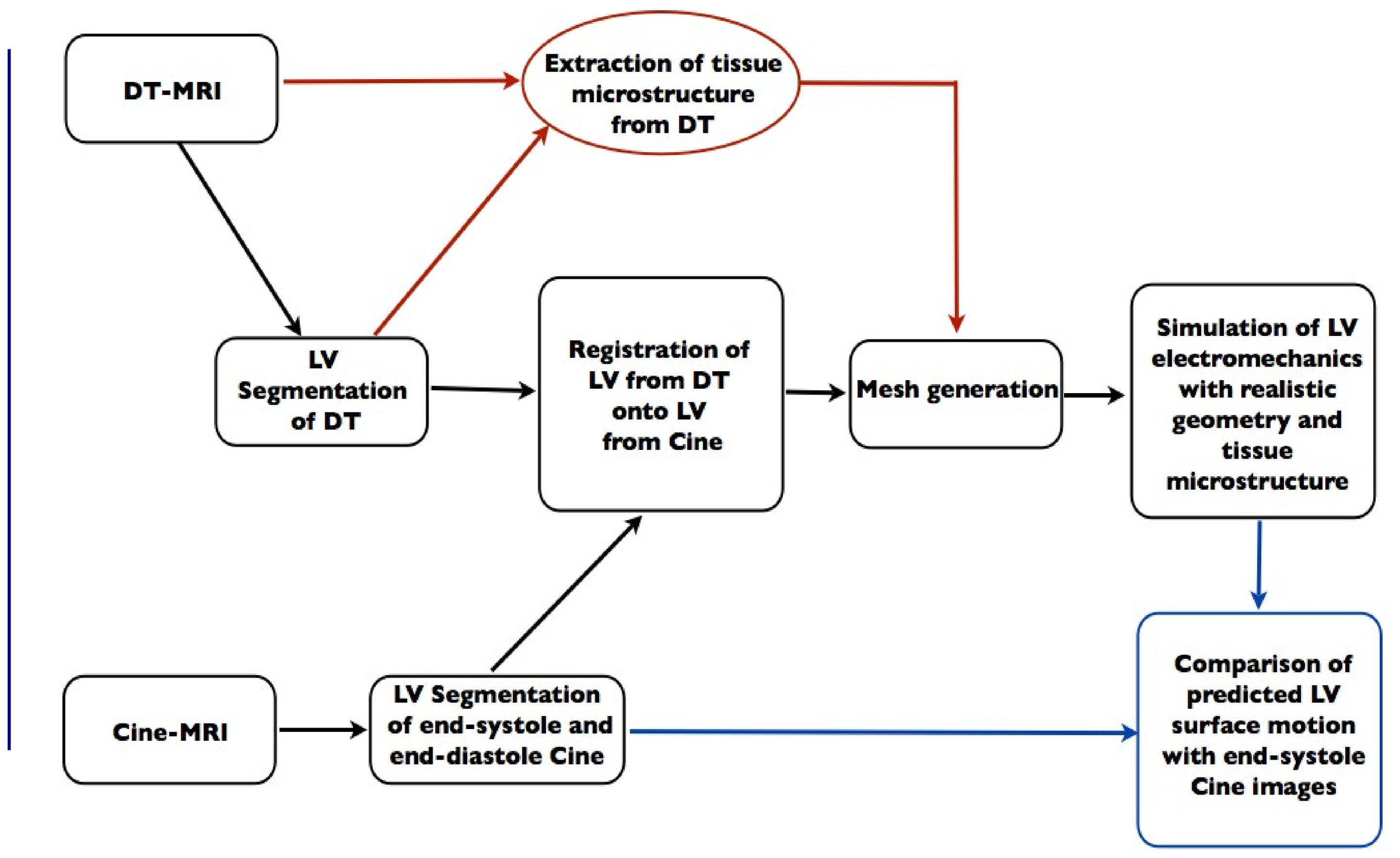
DT-MRI (*ex-vivo*)



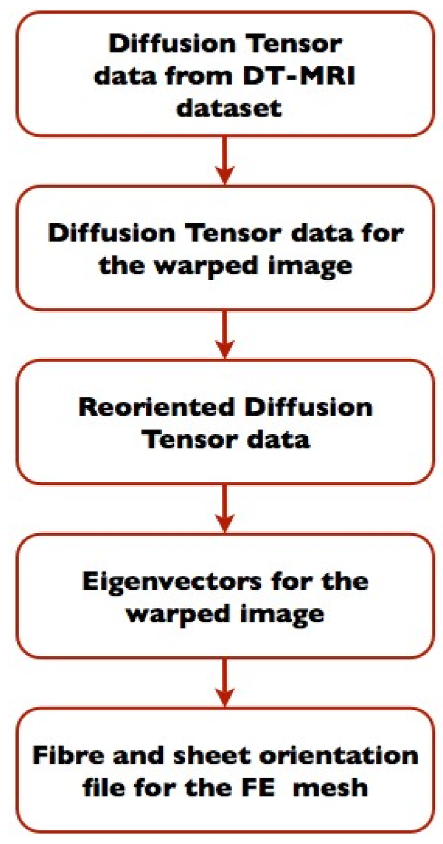
3D+t Cine-MRI (*in-vivo*)

The data were acquired at the University of Oxford (Dr. J. Schneider, Prof. P. Kohl) . More details in [3].

b. Overall pipeline, from image processing to simulation

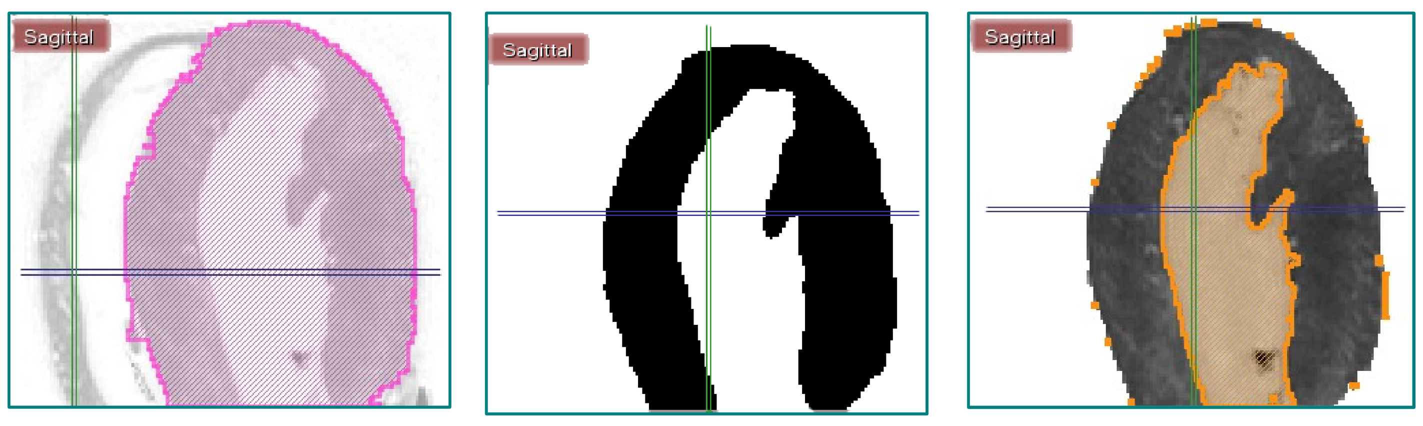


c. Detail of pipeline step of Extraction of tissue microstructure from DT

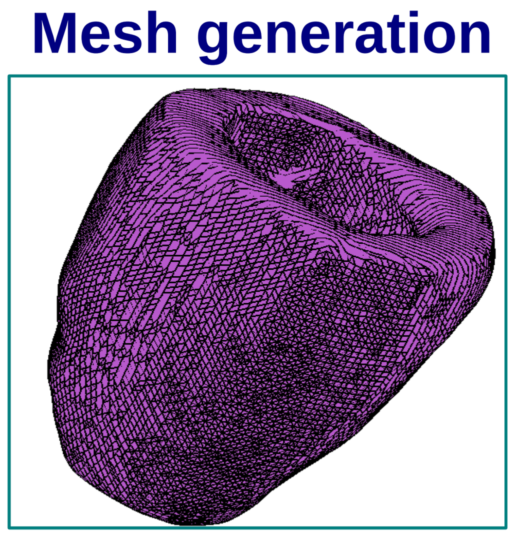


Preliminary Results

Segmentation of DT

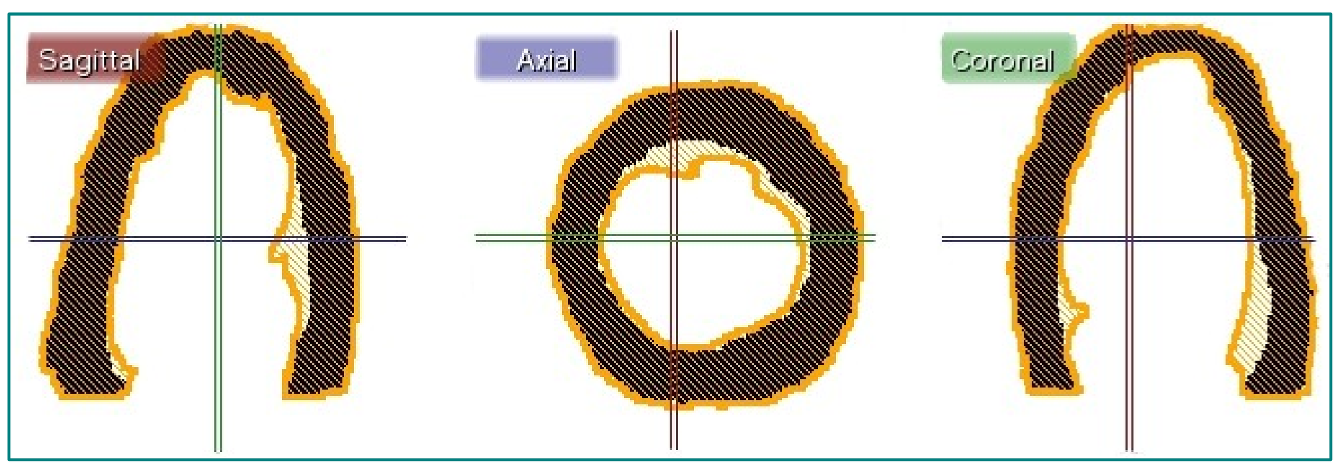


Mesh generation

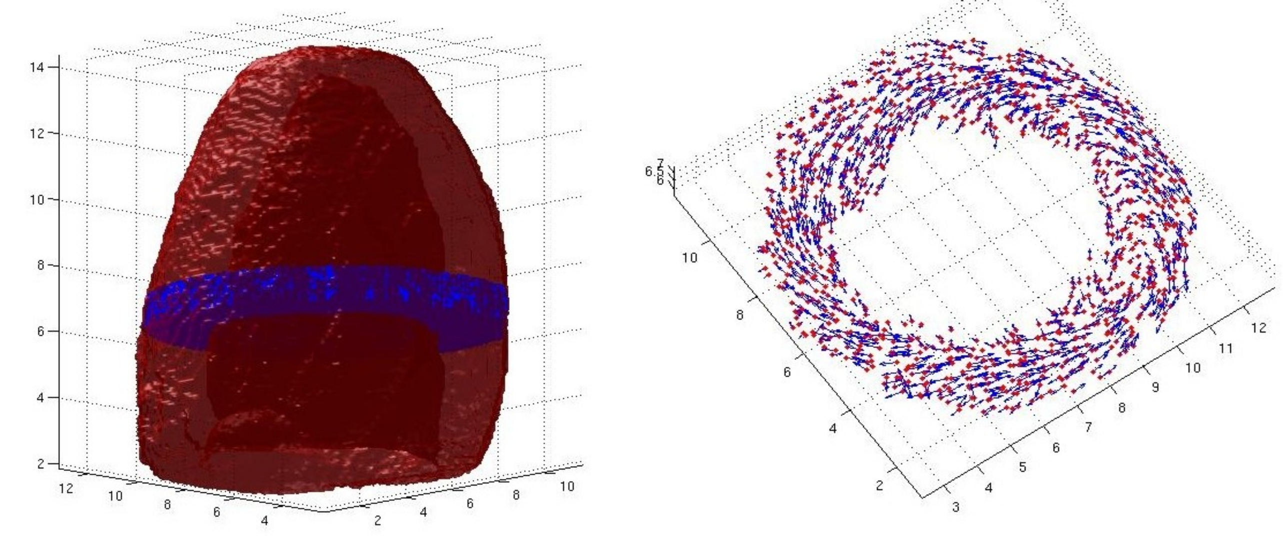


All the phases of the image processing part of the pipeline have been carried out, some of them are here represented. Simulations on the realistic LV geometry, with fibre/sheet orientation extracted form data, will be run within the software environment Chaste [2] and will be preceded by simulations on simplified geometries, specifically a 2D square, 3D cubic wedge and truncated ellipsoid. Preliminary simulations on the 2D square, with prescribed varying fibres and increasing angular noise, are shown in the panel below.

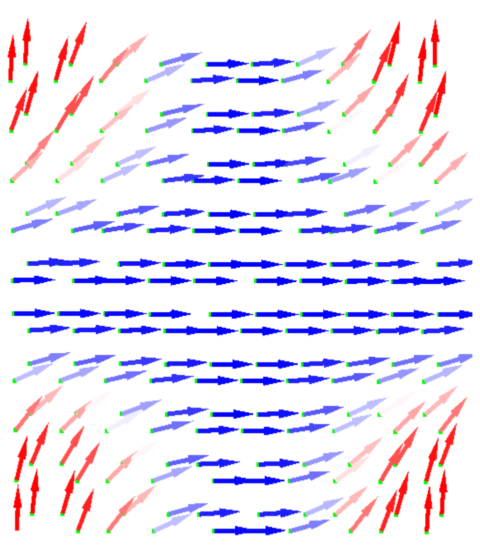
Registration of DT onto Cine



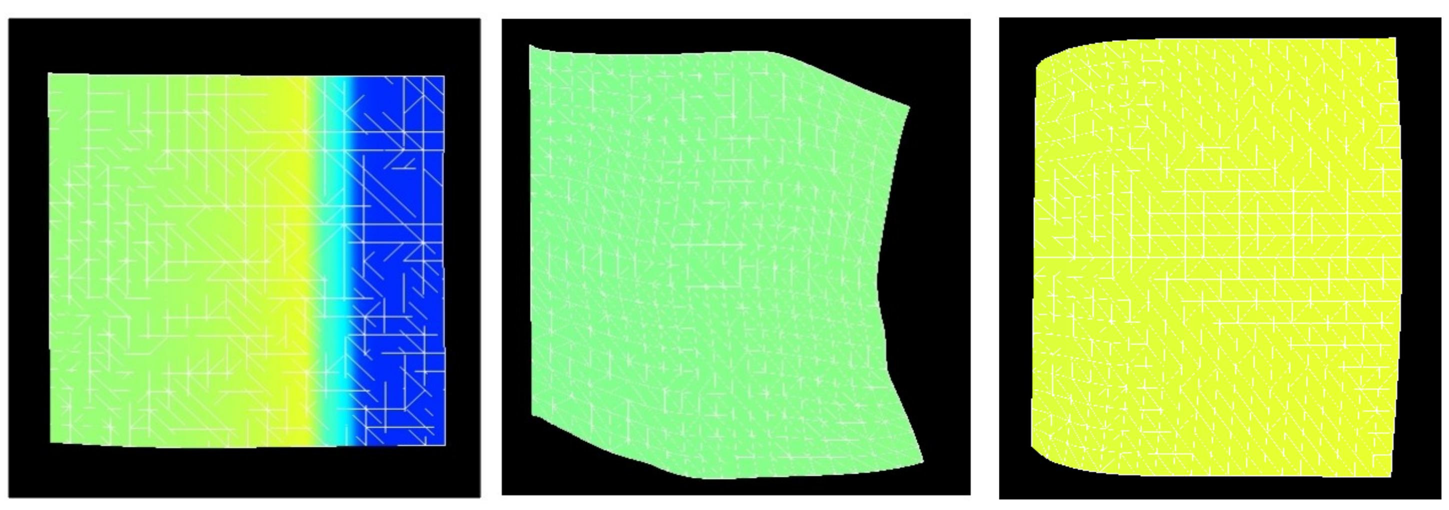
Fibre orientation for the FE mesh



Electromechanical simulations on a 2D square of tissue



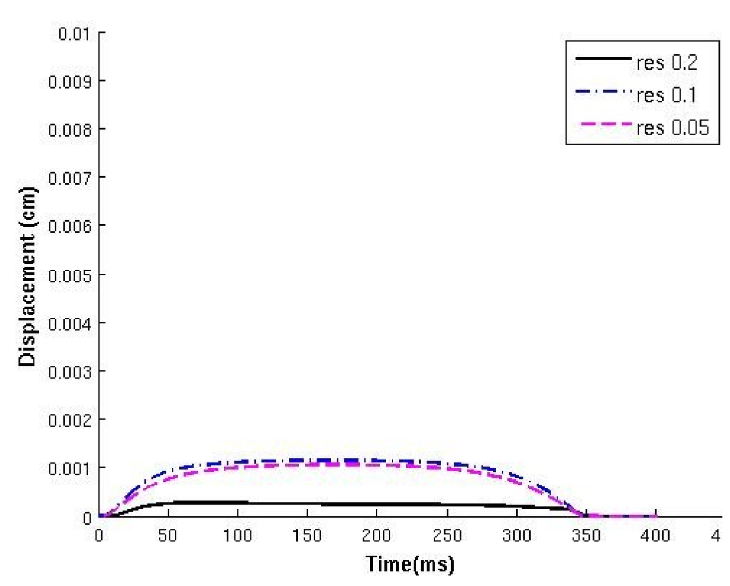
Varying fibres defined on the tissue square.



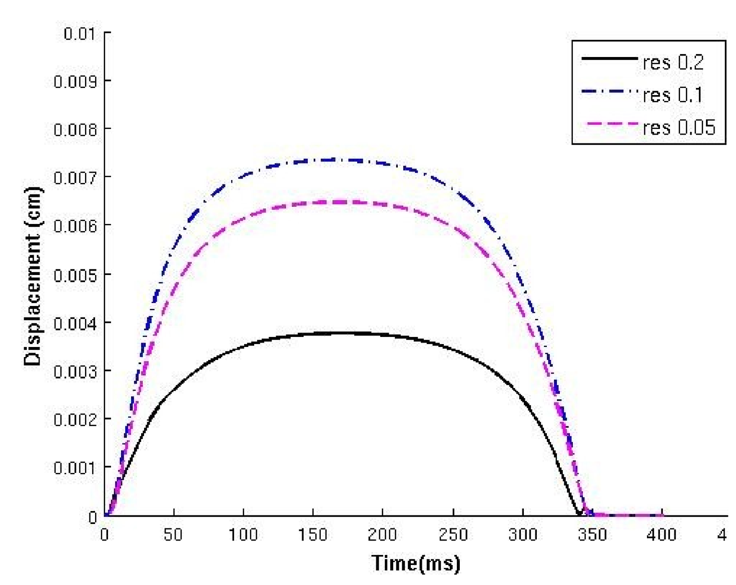
Tissue before contraction

Full contraction with varying fibres

Full contraction with parallel fibres



Displacement with varying fibres and max angular noise 0.1 rad at different mesh resolutions



Displacement with varying fibres and max angular noise 0.3 rad at different mesh resolutions

References

[1] **P. Pathmanathan, J. Whiteley** *A numerical method for cardiac mechanoelectric simulations.* Annals of Biomedical Engineering 37 (2009), no 5, 860-873**.**
[2] **J. Pitt-Francis et al.** *Chaste: A test-driven approach to software development for biological modelling.* Computer Physics Communications 180 (2009), no 12, 2452 – 2471.
[3] **G. Plank et al.** *Generation of histo-anatomically representative models of the individual heart: tools and application.* Physical and Engineering Sciences 367 (2009), no 1896, 2257-2292.

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