

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

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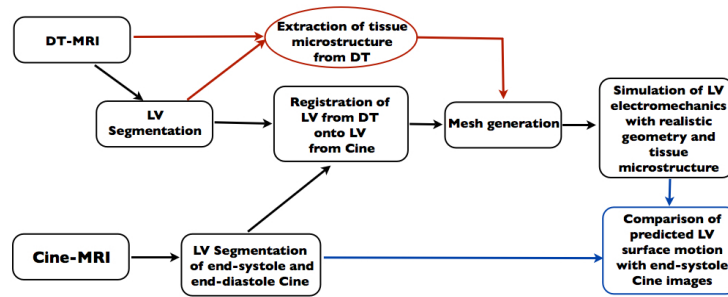
Cardiac motion is a highly integrated process of vital importance as it sustains the primary function of the heart, that is pumping blood. For this reason cardiac motion abnormalities are often associated with severe pathologies. Clinical non-invasive techniques can assess this fundamental connection between motion aberrant behaviour and pathology only to a certain extent. Computational models of heart function would thus be of great help in linking local to global motion abnormalities and to pathology [2]. Such models are based on the description of both cardiac electrophysiological and mechanical behaviour and their coupling, but, while the electrophysiology of the heart is already well characterised from single cell to whole organ level, the mechanical behaviour is still far from being successfully reproduced. No current model of the heart is able yet to realistically simulate motion patterns in the healthy or diseased heart and therefore prediction of clinically relevant parameters such as ejection fraction, stroke volume, wall thickening and wall motion are not fully reliable.

It is well known that cardiac tissue microstructure, that is cardiac cells organisation into fibres and sheets, has an important role in cardiac motion. Fibre orientation provides the direction along which contraction takes place. This type of information is usually embedded into the model by using prescribed, that is mathematically defined, orientations, although in recent years the use of orientations extracted from data of *ex-vivo* diffusion-tensor magnetic resonance imaging (DT-MRI), also called realistic fibre orientations, has become more frequent. Tissue organisation into sheets has also been long experimentally proven and it is considered to greatly contribute to the even distribution of stress and strain through the tissue. Nonetheless, from the modelling point of view, it is not as well characterised [1]. Sheet orientation can be as well prescribed or obtained from histology or from DT-MRI. Both methods have strong limitations and particularly there is not a full understanding of the relation between DT-MRI values and laminar structure.

The hypothesis driving my DPhil is that current models fail to reproduce realistic features of cardiac mechanics because in most cases they do not embed sufficient information about local tissue organisation into fibres and sheets. Tissue structure presents a high level of heterogeneity, it varies in fact regionally, transmurally from endo- to epicardium, temporally over a cardiac cycle and between subjects [3]. All these aspects of tissue structure deeply affect the anisotropy of cardiac tissue, influencing the local patterns of electrical excitation, mechanical deformation and stress generation. Therefore a more realistic representation of tissue structure within an electromechanical model of the heart, with fibre and sheet orientation extracted from data rather than mathematically defined, together with a more careful definition of tissue material properties, would better take into account the high heterogeneity of tissue structure, thus improving the predictive power of the model.

The aim of my DPhil is to investigate how different settings of tissue structural arrangement affect the motion prediction of an electromechanical model applied to a rat left ventricular geometry obtained from magnetic resonance imaging. My research relies on the integration of cardiac imaging data and mathematical modelling in the belief that realistic models of cardiac function need to reach the best compromise between the level of modelling detail and the amount and quality of information that can be actually obtained from data and used either to instruct or validate such models [4].

My research aims at assessing the impact on electromechanics of the sole fibres, and the



**Fig. 1.** Pipeline for model construction, simulation and comparison. The middle sub-diagram (black arrows), shows the geometry extraction from images, the upper chart shows the tissue microstructure extraction from DT-MRI (red), the lower chart shows the comparison step of simulated vs realistic motion patterns (blue).

combined effect of fibre and sheet information. In both cases, the different response due to prescribed or realistic fibres and sheets will be investigated. Finally, the direct comparison will be carried out between the simulated motion patterns and those extracted from *in-vivo* Cine-MRI scans. This imaging technique provides with a series of images at progressive points of the cardiac cycle which can then be used to form a cine loop. The key point is that the DT-MRI scans, from which the geometry and the microstructure used to instruct the model are extracted, and Cine-MRI scans, from which the motion patterns are estimated, have been performed on the same subject.

Figure 1 summarises the pipeline that goes from image processing of DT- and Cine-MRI data, necessary to obtain the input for the computational model, to the electromechanical simulations and finally to the comparison between predicted and data-extracted motion patterns. All the image processing part has already been performed during the first year of my DPhil, while the simulation and comparison phases will be carried out in the successive two years. To the best of my knowledge this is the first attempt to perform a comprehensive study of the importance of tissue microstructure in an electromechanical model and to define a framework that combines electromechanical modelling with the use of imaging data from the same subject to first instruct the model and then validate it.

## References

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