ON THE ANISOTROPY OF THE MYOCARDIUM

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Introduction

Over the years, the description of the passive mechanics of the myocardium has become more and more complex, from an isotropic to an orthotropic material. This has been driven by experimental observations, as the one from Dokos et al. [1]. They subjected to shear tests cubic samples from porcine left ventricles, revealing an orthotropic behavior of the myocardium.

This rises the important question of the microstructural origin of this anisotropy. At the cellular level, the cardiomyocytes are elongated cylinders, suggesting a transversely isotropic behavior. At least two microstructural features could explain the macroscopic anisotropy: The change of orientation of the cardiomyocytes, which varies by 120º over the heart wall thickness; At mesoscale, the cardiomyocytes are arranged into anisotropic bundles surrounded by thicker collagen layers [2].

In order to investigate which effect is required, we designed a multi-scale model of the myocardium, bridging the cell, sheetlet and tissue scales [3]. The model is then optimized to find the microscopic parameters that best match the macroscopic data. This enables us to test the contribution of different mesostructures.

Methods

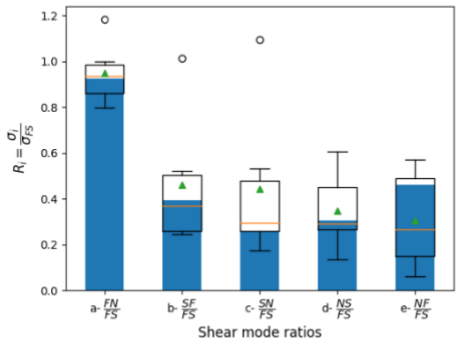
We build different mesostructures combining a transverse isotropic myocardium with different collagen layers architecture. First, we didn't put any collagen, to test the role in the change of cardiomyocytes orientation. Second, we use thin flat layer of collagen between thick layers of myocardium. Third, we use an elliptical shape for the collagen layer, surrounded by myocardium. These microstructures are numerically homogeneized.

Then, they are used to reproduce Dokos et al. experiments [1], by simulating the same shear tests. We included the variations of the myocardium orientation, as well as of the collagen layers, and the mechanical parameters are optimized.

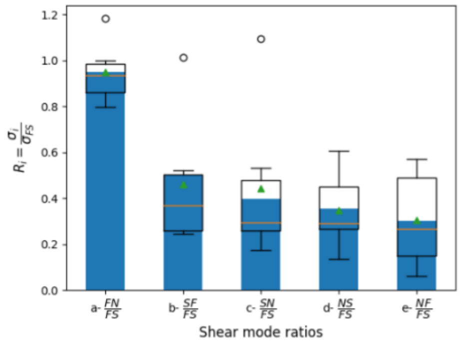
Results

Results for the optimal models based on homogeneous and stratified mesostructures are shown on the figure (1). Elliptical mesostructure lead to results similar to stratified mesostructure.

The model without collagen layer is not able to reproduce the experimental data, showing the importance of the layer arrangement and their rotation in the heart thickness.



(a) Homogeneous mesostructure.



(b) Stratified mesostructure.

Figure 1: Comparison of experimental (box plot with mean in green triangle, median in orange line) and theoretical (blue bar plot) shear stresses (normalized with respect to largest value) – figure from [3].

Conclusions

The variation of myofiber orientation through the myocardium, without mesostructure such as collagen planes, does not allow to describe the measured anisotropy at the macroscopic scale. Conversely, by taking into account the microstructural organization at the sheetlet scale, and the variation of the sheetlet orientation through the ventricle, it is possible to reproduce the macroscopic data. An additional finding is that some level of compressibility is required to fit the data. These findings call for a more thorough analysis of the mesostructural arrangement of the myocardium, and its role on the ventricular mechanics.

References

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