Stochastic variational inference for myocardial constitutive models using heterogeneous displacement fields

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Abstract

The myocardium exhibits highly non-linear hyperelastic and orthotropic material behavior during passive deformation. Over the past few decades, many material models have been proposed, with one of the most popular ones being the microstructure-inspired constitutive model formulated by Holzapfel and Ogden (1). It has been shown that an accurate characterization of this material model based on homogeneous tissue experimentation is no easy task (2) and requires the excitation of multiple deformation modes, e.g. combined triaxial shear tests and biaxial stretch tests (3).
Inherently, such multimodal experimental protocols necessitate multiple tissue samples and extensive sample manipulations. Intrinsic inter-sample variability and manipulation-induced tissue damage might have an adverse effect on the inversely identified tissue behavior.

In this work, we aim to overcome this gap by focusing our attention to the use of heterogeneous deformation profiles in a parameter estimation problem. More specifically, we extend EUCLID, an unsupervised method for the automated discovery of constitutive models (4), towards highly non-linear, orthotropic materials using a Bayesian inference approach and three-dimensional continuum elements. We showcase its strength to qualitatively infer – with varying noise levels – the material model parameters of in-silico myocardial tissue slabs from a single heterogeneous biaxial stretch test. This method shows good agreement with the ground truth simulations and with corresponding credibility intervals for each parameter. Our work highlights the potential for characterizing highly nonlinear and orthotropic material models from a single biaxial stretch test - an approach long deemed to be infeasible.

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