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Research paper

A mesostructurally-based anisotropic continuum model for biological soft tissues—Decoupled invariant formulation

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A B S T R A C T

Characterising and modelling the mechanical behaviour of biological soft tissues is an essential step in the development of predictive computational models to assist research for a wide range of applications in medicine, biology, tissue engineering, pharmaceutics, consumer goods, cosmetics, transport or military. It is therefore critical to develop constitutive models that can capture particular rheological mechanisms operating at specific length scales so that these models are adapted for their intended applications.

Here, a novel mesoscopically-based decoupled invariant-based continuum constitutive framework for transversely isotropic and orthotropic biological soft tissues is developed. A notable feature of the formulation is the full decoupling of shear interactions. The constitutive model is based on a combination of the framework proposed by Lu and Zhang [Lu, J., Zhang, L., 2005. Physically motivated invariant formulation for transversely isotropic hyperelasticity. International Journal of Solids and Structures 42, 6015–6031] and the entropic mechanics of tropocollagen molecules and collagen assemblies. One of the key aspects of the formulation is to use physically-based nanoscopic quantities that could be extracted from experiments and/or atomistic/molecular dynamics simulations to inform the macroscopic constitutive behaviour. This effectively couples the material properties at different levels of the multi-scale hierarchical structure of collagenous tissues. The orthotropic hyperelastic model was shown to reproduce very well the experimental multi-axial properties of rabbit skin. A new insight into the shear response of a skin sample subjected to a simulated indentation test was obtained using numerical direct sensitivity analyses.

1. Introduction

Characterising and predicting the mechanical behaviour of biological soft tissues is an essential requirement for conducting computer experiments using finite element or computational fluid dynamics techniques. The domains of application have expanded well beyond medicine and automotive safety to reach other fields such as consumer products, cosmetics (Limbert, 2009), sports equipment or computer graphics. It is therefore critical to develop

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