A Thermodynamic framework for the mechanically driven remodelling and fiber reorientation in soft biological tissues

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Abstract

Fiber alignment in soft biological tissues is governed by cellular responses to mechanical stimuli arising from the properties of the surrounding material. This interaction, which couples mechanical anisotropy with tissue remodelling, can be effectively captured through fibre-reinforced hyperelastic models. In this study, we present a thermodynamics-based framework for modelling fibre reorientation, emphasizing the role of the second law of thermodynamics in governing the remodelling process. Fibre reorientation is modelled analytically in a rectangular elastic tissue reinforced with two symmetrically arranged fibre families subjected to constant external loads. The framework predicts fiber alignment with the maximum principal stretch and demonstrates that the system converges to stable equilibrium states. This modelling approach is robust across a wide range of material parameters and loading conditions, providing a comprehensive understanding of tissue adaptation mechanics. Insights from prior experimental studies on vascular remodelling and arterial wall mechanics during pathological conditions, such as hypertension and abdominal aortic aneurysm (AAA) progression, are incorporated. Structural and mechanical data are integrated into the model, revealing connections between collagen fibre orientation, anisotropic material behaviour, and disease progression.

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