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Magic angles and fibre stretch in arterial tissue: insights from the linear theory

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Abstract

This work is motivated by the current widespread interest in modelling the mechanical response of arterial tissue. A widely used approach within the context of anisotropic nonlinear elasticity is to use an orthotropic incompressible hyperelasticity model which, in general, involves a strain-energy density that depends on seven independent invariants. The complexity of such an approach in its full generality is daunting and so a number of simplifications have been introduced in the literature to facilitate analytical tractability. An extremely popular model of this type is where the strain energy involves only three invariants. While such models and their generalisations have been remarkably successful in capturing the main features of the mechanical response of arterial tissue, it is generally acknowledged that such simplified models must also have some drawbacks. In particular, it is intuitively clear that the correlation of such models with experiment will suffer limitations due to the restricted number of invariants considered. Our purpose here is to use the linearised theory for infinitesimal deformations to provide some guidelines for the development of a more robust nonlinear theory. The linearised theory for incompressible orthotropic materials is developed and involves six independent elastic constants. The general stress-strain law is inverted to provide an expression for the fibre stretch in terms of the stress. We examine the linearised response for simple tension in two mutually perpendicular directions corresponding to the axial and circumferential directions in the artery, obtaining an explicit expression for the fibre stretch in terms of the applied tension, fibre angle and linear elastic constants. The focus is then on determining the range of fibre orientation angles that ensure that the fibres are in tension in these simple tension tests. It is shown that the fibre stretch is positive for both simple tension tests if and only if the fibre angle is restricted to lie between two