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MODELLING STRONG FIBRE ALIGNMENT IN THE COLLAGEN NETWORK OF BIOMEMBRANES

Alexander E. Ehret, Arabella Mauri and Edoardo Mazza

Institute of Mechanical Systems, ETH Zurich, Tannenstr. 3, 8092 Zurich, Switzerland,
ehret@imes.mavt.ethz.ch, www.imes.ethz.ch

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The mechanical behaviour of collageneous biological membranes separating phases, tissues and organs has gained large scientific interest both in terms of experimental investigations and modelling over the past decades, see e.g. [1, 2]. Recent experimental results on the amnion layer of the fetal membrane reveal extremely large lateral contraction upon uniaxial extension, along with a non-linear stress response [3]. Second harmonic generation microscopy of fetal membranes [4] and studies on collagen gels [5, 6] suggest that this marked Poisson effect is related to strong alignment of fibres in the network.

Starting from the general theory of plane stress for transversely isotropic materials [7], we present in this contribution a model for biological membranes that accounts for strong alignment of fibres in a planar collagen network. Following the idea of an orientation tensor originally proposed to account for cell alignment in tissue equivalents [8], we perform stretch averaging over a set of non-affinely deforming fibres and, by this means, obtain an average stretch in terms of an analytical expression. From energetic considerations, it is shown that the achievable limit of lateral contraction in a uniaxial tension experiment includes the experimentally reported behaviour for various tissues. Incorporating this average stretch in a strain-energy function, excellent agreement of the hyperelastic model with uniaxial tension data [3] is obtained both in terms of stress and the kinematic response.

Finally, the proposed model is used in numerical simulations and compared to a discrete finite element representation of a planar random fibre network which likewise captures both the non-linear response and the strong lateral contraction. Commonalities and differences in terms of model predictions and performance between the continuum and discrete approach are highlighted and discussed.

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