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

Key words: Biological Membranes, Non-affine Deformations, Fibre Networks, Average
Stretch, Poisson effect.

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 uni-
axial 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.
REFERENCES


