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A Multi-Scale Model for the Mechanics of the Human Lens Capsule

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ABSTRACT

The human lens consists of an intricate arrangement of cells (the lens substance) enclosed within a thin collagen-rich capsule. The capsule and substance are generally represented as distinct materials in any numerical model of the mechanical performance of the lens (e.g., to study the accommodation mechanism).

The model described in this paper represents the mechanics of the capsule at two different scales. At the macroscopic scale, the capsule is modelled as a membrane using an axisymmetric hyperelastic finite element approach. At the microscopic scale, the constitutive behaviour of the capsule is represented by a structural model (termed 'micronet') that is based on a detailed representation of the capsule ultrastructure [1].

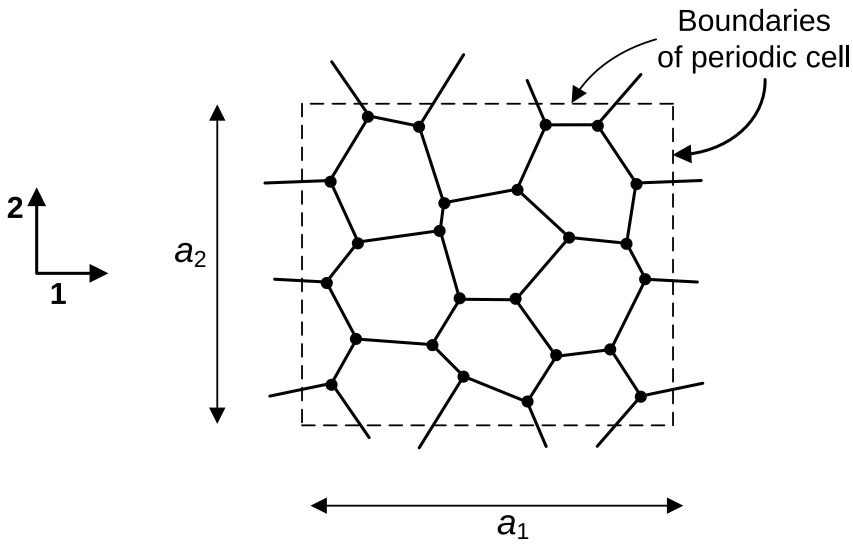

Figure 1: Geometric arrangement of bars in the micronet model. Reproduced from Burd [1].

The micronet model consists of an irregular hexagonal mesh of non-linear elastic bars generated within a periodic cell (to represent the mechanical behaviour of the collagen IV network within the capsule) embedded in a neo-Hookean matrix (see Fig. 1). The strain-energy function, W (defined per unit reference area), is

$$W \ = \ w_n(\lambda_1, \lambda_2) \ + \ w_m(\lambda_1, \lambda_2), \tag{1}$$

where w_n is the component of strain energy associated with the collagen network, w_m is the component of strain energy associated with the neo-Hookean matrix and λ_1, λ_2 are the principal stretch ratios in the plane of the capsule. Procedures are described in the paper to compute the first and second derivatives of W with respect to the two principal stretch ratios. These derivatives are used to define the constitutive behaviour of the capsule in the macroscopic finite element analysis.

This multi-scale model is used to develop an axisymmetric finite element analysis of the capsule inflation test described by Fisher [2] for a 30-year capsule. (In this test, a portion of anterior capsule was inflated by a fluid, and measurements were made on the volume of fluid used to inflate the capsule and the corresponding pressure, see Fig. 2). The computed results correspond closely to the published experimental data.

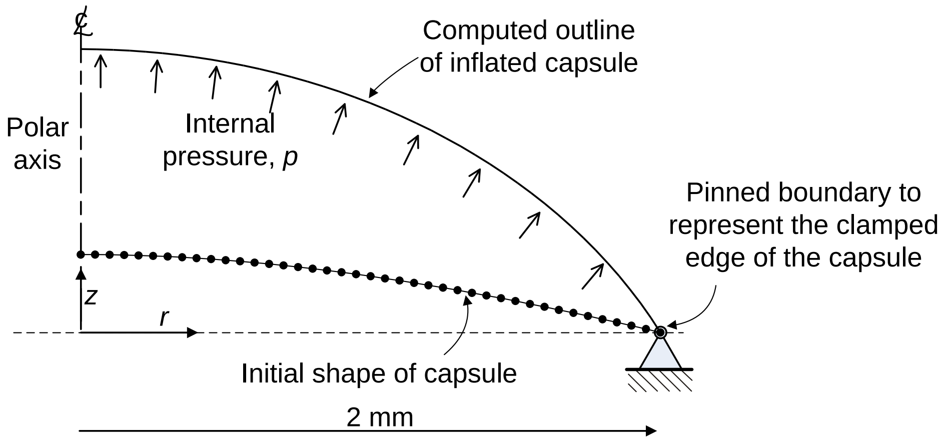

Figure 2: Fisher [2] inflation test (shown in diagrammatic form).

This multi-scale model has also been used to analyse the capsule inflation test described by Pedrigi et al. [3]. In this test procedure, the capsule of an intact *in-vitro* lens was inflated by the injection of fluid at the interface between the capsule and the lens substance. This causes an anterior portion of the capsule to become detached from the lens and inflated by the fluid. Computed data on the inflation pressure vs. Green strain for the capsule shows good agreement with the experimental data reported by Pedrigi et al. [3].

References

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