Determination of the local mechanical properties of the aortic leaflet using simple indentation

Determination of the local mechanical properties of the aortic valve leaflet using simple indentation

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Introduction

To withstand diastolic pressures, the aortic valve leaflets have developed a well-organized collagen fiber architecture (Figure 1). As a results of this, the leaflet exhibits highly nonlinear, anisotropic and inhomogeneous mechanical behavior [1]. Experimental techniques are required to determine these local mechanical properties. We state that using simple indentation tests, collagen fiber distribution and mechanical properties can be obtained from analysis of the local tissue deformation gradient and the reaction force at various indentation depths.
The advantages of simple indentation tests over more common uni- or multiaxial testing are: 1) experiments are easy to perform; 2) mechanical properties can be obtained *locally*.

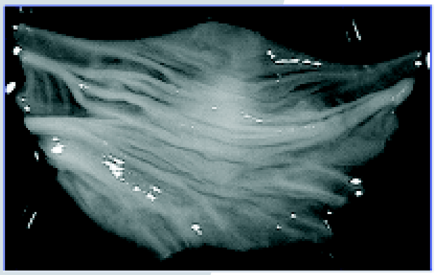

Figure 1 *Collagen fiber distribution in the native aortic leaflet.*

Methods

A preliminary computational study has been carried out to simulate the indentation test. A tissue sample of 3 x 3 x 0.5 mm^3 is modeled as an incompressible fiber-reinforced material. The tissue is compressed between a spherical indenter (radius = 0.5 mm) and a rigid (glass) surface (Figure 2). The collagen fibers are represented by a discrete, Gaussian distribution [1, 2]. The fiber distribution is varied from tight (one fiber direction) to broad (uniform distribution), while total fiber volume fraction is kept constant.

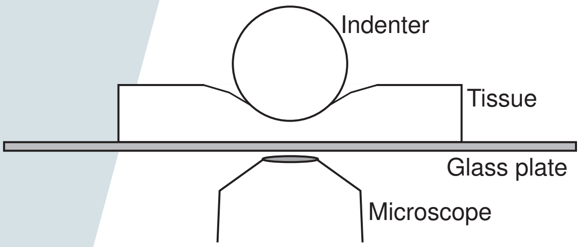

Figure 2 *Schematic representation of simulated experiment. Set-up can be placed on an inverted confocal microscope to quantify tissue stretch.*

Results

Principal stretch directions at the glass surface, in the vicinity of the indenter, coincide with the material axes. Maximal stretch is found perpendicular to the main fiber direction. For a tight fiber distribution, large differences are found between principal stretches. In the native valve simulation, fiber spreading leads to collagen locking in both directions at >50 percent global indentation, which yields a large increase in the reaction force at the glass surface (Figure 3). This effect was observed earlier by Driessen et al. in biaxial stress simulations of the aortic valve leaflet [2].

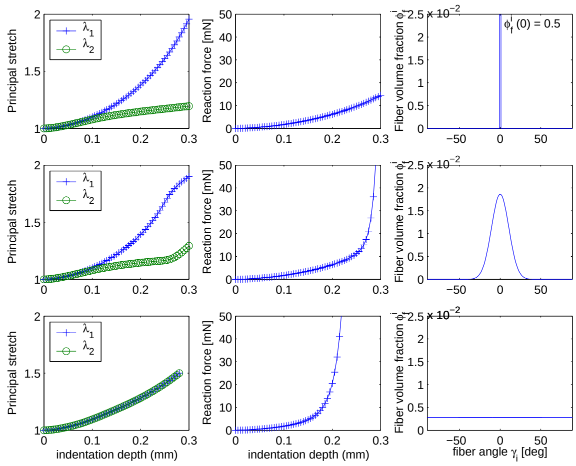

Figure 3 *First* (λ_1) *and second* (λ_2) *principal stretch at indenter location (left), and reaction force (middle), for three different fiber distributions (right). Top row: one fiber direction, middle row: native valve fiber distribution[1], and bottom row: uniform distribution.*

Discussion

- ☐ Principal stretch analysis of spherical indentation tests can be used to determine local fiber direction.
- ☐ Tissue mechanical response is dependent of angular fiber distribution.
- ☐ Collagen locking and in-plane axial coupling is observed for native valve at 50 percent global indentation.

Future work

- ☐ Numerical feasibility study on the quantitative determination of fiber distribution and material parameters using simple indentation and parameter estimation.
- ☐ Experimental quantification of local mechanical properties of heart valve leaflet using simple indentation.

References:

[1] Billiar KL, Sacks MJ: *JBME, 2000, 122: 327-335*
[2] Driessen NJB, et al.: *JBME, submitted*