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Mechanical characterization of planar soft biological tissues

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Introduction
Current methods for mechanical characterization are insufficient for a full characterization of the typical non-linear, anisotropic and inhomogeneous material behavior of planar soft biological tissues, such as skin, blood vessels or heart valve leaflets.

Objective
Development, validation and application of a method for the non-destructive, local mechanical characterization of planar soft biological tissues using spherical indentation.

Methods
An indentation device is mounted on top of an inverted confocal microscope (CLSM). The indentation depth and force are measured by the indentation device. Digital Image Correlation (DIC) is applied to the confocal images to quantify tissue deformation during indentation (Fig. 1).

A numerical model is coupled to the experimental results for mechanical parameter estimation. The tissue is modeled as an incompressible fiber-reinforced material [1]. The extra stress $\tau$ is given by an isotropic matrix stress $\tau_m$ and a fiber stress $\psi_f$, which works in the fiber direction $\vec{e}_f$ only:

$$\tau = \tau_m + \sum_{i=1}^{N_f} \phi_f^i \left[ \psi_f^i - \overline{c}_f^i \cdot \tau_m \cdot \overline{c}_f^i \right] \overline{c}_f^i \overline{c}_f^i .$$  (1)

A Gaussian fiber distribution is modeled by a discrete number of fibers $N_f$ with a volume fraction of $\phi_f^i$ each.

Results
A computational study showed that one single indentation test provides sufficient information to characterize the local, nonlinear, anisotropic behavior of soft biological tissues [2]. Indentation depth and force alone suffice for characterization of the isotropic behavior. Experimental validation was performed on linear elastic PDMS rubbers and identical results were found for indentation and uniaxial tensile tests.

Mechanical characterization was performed of epiderm and bioartificial muscle (BAM), (Fig. 2). The experimental data was fit well by a nonlinear Neo-Hookean model. Results indicated that BAM’s seeded with cells were significantly stiffer and more nonlinear than without cells after 4 weeks of culturing.

Indentation tests revealed inhomogeneous mechanical behavior for tissue engineered heart valve (TEHV) leaflets after 4 weeks of culturing. Different behavior was found for the belly (center) and the commissure (edge) of TEHV leaflets (Fig. 3).

Future work
For the estimation of anisotropic mechanical properties, a quantitative agreement needs to be found between deformation gradients during indentation from experiments and simulations. Preliminary findings on TE constructs indicate a reasonable qualitative agreement (Fig. 4). Parameter estimation will be performed to achieve a quantitative fit.

References: