Mechanical characterization of planar soft biological tissues

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Martijn A.J. Cox, Niels J.B. Driessen, Carlijn V.C. Bouten, Frank P.T. Baaijens
Eindhoven University of Technology, Department of Biomedical Engineering

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).

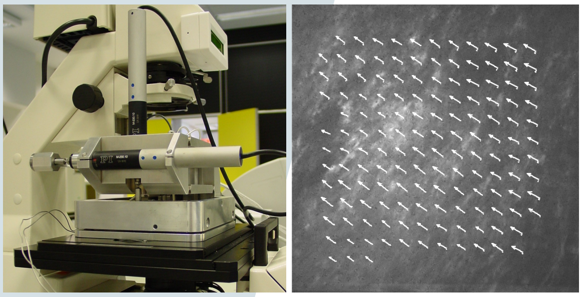

Figure 1 *Indentation device on top of an inverted CLSM (left). Tissue engineered (TE) construct during indentation, first principal stretch directions are indicated with arrows (right).*

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 $\boldsymbol{\tau}$ is given by an isotropic matrix stress $\boldsymbol{\tau}_m$ and a fiber stress ψ_f, which works in the fiber direction $\vec{e}_f$ only:

$$\boldsymbol{\tau} = \boldsymbol{\tau}_m + \sum_{i=1}^{N_f} \phi_f^i \left[\psi_f^i - \vec{e}_f^{\,i} \cdot \boldsymbol{\tau}_m \cdot \vec{e}_f^{\,i} \right] \vec{e}_f^{\,i} \vec{e}_f^{\,i}. \qquad (1)$$

A Gaussian fiber distribution is modeled by a discrete number of fibers N_f with a volume fraction of ϕ_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.

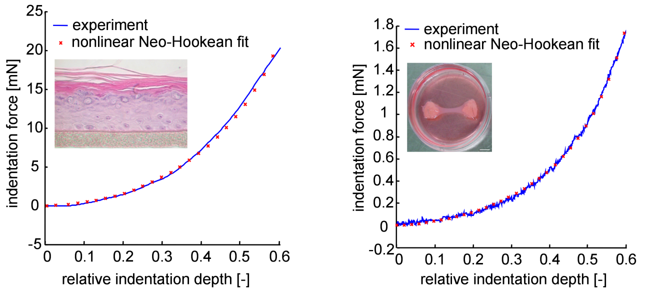

Figure 2 *Numerical fit of an indentation test on epiderm (left) and BAM (right) using a nonlinear Neo-Hookean material model.*

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).

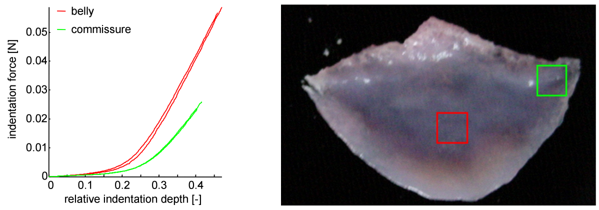

Figure 3 *Indentation test (left) on the belly (red) and commissure (green) of a TEHV leaflet (right) after 4 weeks of culture time.*

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.

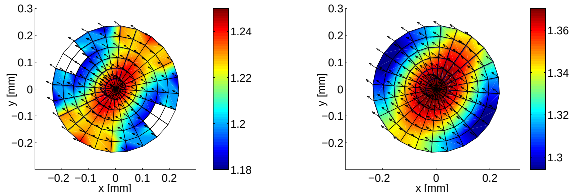

Figure 4 *Magnitude and direction of first principal stretch at 20% indentation of a TE construct: experiment (left) and simulation (right).*

References:

[1] DRIESSEN NJB, ET AL. : *JBME, 127(3), 2005*

[2] COX MAJ, ET AL.: *JBME, 128(3), 2006*