THE INFLUENCE OF SUPRA-PHYSIOLOGICAL LOADING ON MECHANICAL AND MICROSTRUCTURAL TISSUE QUANTITIES

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Introduction

Clinical treatment of obstructed lumens, generally caused by advanced atherosclerosis, often includes balloon angioplasty, a procedure involving the overstretching of arterial walls into the supra-physiological domain. The resulting stress-softening of the collagenous wall tissue is believed to arise from treatment induced microscopic damage, which we model using a new damage function (based on [Balzani et al., 2012] and [Scott, 2003]) which includes the evolution of statistical distributions of experimentally determined biomechanical and microstructural quantities as a function of overstretch. Towards that end layer-specific cyclic tension-tests were utilized on healthy as well as on collagenase and elastase treated human arterial tissues to investigate component-specific stress softening behavior. Second-harmonic generation (SHG) imaging was performed to visualize structural changes to the collagen fiber network. Electron microscopy (EM) imaging yielded micrographs showing collagen fibrils and proteglycan (PG) bridges, from which we determined statistical distributions of interfibrillar distances and PG bridge orientations.

Methods

Cyclic tension-testing was performed on the adventitia and the media of human abdominal aortas. From each aortic specimen three circumferential strips were extracted: one was treated with collagenase [Dobrin, 1984], one with elastase including trypsin inhibitor [Missirlis, 1977], and one was left untreated for control. For each load step 10 load cycles were performed, before progressively increasing the load until rupture. From each specimen small samples were taken before and after mechanical testing for histological investigations using optical, SHG and EM imaging. Image analysis was performed using custom programmed code to extract distributions of distances between intrafibrillar collagens and angular orientations of PG bridges.

Results

Mechanical testing showed an isotropic tissue response for the collagenase treated samples, a damage induced softening effect for the elastase treated samples and a 'normal' response for untreated tissue. The analysis of SHG and EM images yielded for the first time quantitative structural data regarding intrafibrillar collagen distances and PG bridge orientations in human arterial tissue before and after supra-physiological loading.

Discussion

The macroscopic response of the fiber-reinforced arterial tissue is described by a formulation based on micro-mechanical models characterizing the individual tissue components. For this model, mechanical and microstructural tissue quantities from before and after overstretching are required which we determined experimentally, yielding novel insights into the effect of supra-physiological loading on the human arterial wall.

References

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