EXPERIMENTAL AND MODELLIND ANALYSES FOR UNDERSTANDING OF THE STRUCTURE-MECHANICS RELATIONSHIP OF AORTIC TISSUE

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Introduction

The analysis of the microstructural characterization of soft biological tissues plays a key role in the understanding of their mechanical response and remodeling. Soft tissues, such as aorta walls, can be regarded as fibrous materials assembled from a ground matrix. Alterations occurring to the embedded of collagen fibers have been shown to play a significant role in the pathogenesis of aortic degeneration. Through experimental and modeling analysis, the aim is to study the existing, and yet not well understood, relationship between mechanics and microstructure of healthy and pathological arterial tissues, by combining digital image correlation (DIC), small-angle light scattering (SALS), and multiscale computational modelling.

The study was conducted on pathological tissue samples, specifically affected by aneurysm. An aortic aneurysm is a local bulge of the aorta characterized by segmental weakening of the blood vessel. Irregular hemodynamics have been shown to accelerate the progression of such pathology with a common basis provided by diabetes, male sex, smoking, and hypertension. In addition, imbalance of tissue biochemical pathways results in the onset of pathological remodeling and thus histological changes that affect vascular mechanics [1].

Methods

To understand the relationship between microstructure and mechanical response of arterial tissue, experimental tests and computational modeling analyses were performed. The experimental mechanical characterization of pathological aortic tissue samples is made through biaxial force-controlled tensile test at different tensile ratios, both along the circumferential and axial direction. Using imaging techniques such as DIC, first the displacement and then the strain field could be accurately identified to reconstruct stress-strain curves σ-E.

A second imaging technique, namely SALS, is used to investigate the microstructure. By performing simultaneously with the tensile test, information on the preferential orientation and dispersion of collagen fibers during mechanical loading could be provided.

At the same time, to perform the modeling analysis, arterial tissue was described a nonlinear hyperplastic material.

Using a micro-macro perspective for the mechanics of crimped fibers. In fact, the straightening of crimped fibers in biological soft tissues is responsible for their nonlinear macroscopic mechanical response.

Therefore, the stress-strain curve takes the characteristic J-shaped curve, by explicitly depending on a set of clearly observable microstructural parameters [2].

A finite element implementation of such multiscale modelling technique is also considered, to reproduce the non homogeneous strain field as obtained from DIC image. For the finite element discretization, quadrilateral elements have been introduced, generated in AceGen. In each material point of the domain the presence of crimped fibers in their undeformed configuration was considered, with different orientations as read from SALS measures Other microstructural parameters, e.g, radius amplitude and orientation, were calibrated through a process of parametric identification and numerical optimization for a fixed tension ratio 1:1.

Results

The comparison between the experimental-modeling results demonstrated the validation of the proposed model, showing the relationship existing between microstructure and mechanics in the arterial tissues.

The results obtained are not only representative of the mean mechanical response, but also of the dispersion of strain in the tissue, as obtained from DIC. This correspondence, albeit with different degrees, is maintained even moving away from the calibration condition of the model, defined for the tension ratio 1:1, towards different tension ratios.

Another important result is that the model is also representative of the tissue behavior in terms of collagen fiber realignment, as obtained from SALS measures during mechanical loading.

Discussions

The present work has shown how a multiscale modelling technique is predictive of the mechanical response but also of the microstructure in terms of fiber thickness, amplitude, and orientation of the collagen fibers, during loading. The strong interconnection between mechanics and microstructure is hence highlighted, developing a predictive toll than can serve in future studies of tissue remodelling.

References

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