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Composite synthetic vascular prosthesis design for small diameter artery replacement

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Introduction

Failure of small diameter (< 5 mm) synthetic prostheses is often contributed to a mechanical mismatch with the host artery [1], [2]. Our objectives:

- development of a small diameter synthetic vascular prosthesis which is mechanically compatible with the host artery
- design based on an experimentally validated computational model

Method

Mechanical characterisation

In an experimental setup the artery is subjected to internal pressure being suspended under axial extension. Real-time diameter measurement is performed using Ultrasound. These experiments provide material properties in longitudinal and axial directions. The applied loading is dynamic to investigate viscoelastic properties.

Computational framework

The model is based on a FE implementation of geometrically and physically nonlinear material. Incompressibility is incorporated using a mixed formulation and the balance equations are solved using an integrated method.

Constitutive model

The matrix-fiber structure is modeled using a new composite model:

\[ \sigma = -pI + \dot{\tau} + \sum_{k=1}^{N} \theta_k (\psi_k - \vec{c}_k \cdot \dot{\tau} \cdot \vec{c}_k) \vec{c}_k \vec{c}_k \]

Initially a simplified analytical model is used to fit the experimental data.

Prototype development

The prototype consists of a viscoelastic matrix (hydrogel) which is reinforced with non-linear elastic fibers (Lycra) to obtain material properties that match those of arteries. Design parameters are derived from the numerical model to give an optimized fiber layout.

The fibers are fully embedded in the matrix to give extra strength to the graft and to provide better biocompatibility.

Results

Several results are presented in figure 1 and 2.

Discussion

- tests on natural arteries and hydrogel grafts
- fiber reinforced hydrogel tubes show better results than existing prostheses with respect to matching mechanical behavior of natural arteries
- there is still a mechanical mismatch between the artery and the prosthesis but it is likely that this mismatch can be eliminated

References: