SEARCHING FOR THE MATERIAL PARAMETERS OF THE CONSTITUTIVE MODELS OF THE BLOOD VESSEL WALLS

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1. Introduction

In the past decades many researchers have presented a number of constitutive models of the material that builds up soft tissue of the blood vessel walls. A considerable collection of the models complete with the description can be found in [6]. The need to deliberate theoretically on the theme of modelling this type of material has extensive grounding. Detailed recognition and understanding of the mechanics of the tissue that builds up the wall of the blood vessel is key in order to be able to forecast the change in biomechanical properties of the tissue at different stages of diseases. It is also key in order to be able to model the processes of interaction between the tissue of the wall of the blood vessel and the objects introduced inside the blood vessel. An example of such an object can be stents [1,10] or nanoparticles introduced into the circulatory system, whose task is to deliver medications to a precisely selected location within the human body [9].

2. Constitutive models of the blood vessel wall material

Constitutive models of the tissue making up the walls of the blood vessels have different degrees of simplification – from homogeneous, single-layer, characterised by isotropy, to non-homogeneous, taking anisotropy of the layers that build the tissue of blood vessel walls into account. One example of a single-layer, isotropic model is the model presented by Delfino et al [2]:

$$\overline{\Psi} = \frac{a}{b}\left\{\exp\left[\frac{b}{2}\left(\overline{I}_1 - 3\right)\right] - 1\right\}, \tag{1}$$

where *a* is a stress-like material parameter and *b* is a non-dimensional parameter, *a* and *b* should be larger than 0.

One example of a non-homogeneous model that takes anisotropy of the material through reinforcement by adequately positioned types of collagen fibers into account is the model presented by Holzapfel et al [3,4,5,6]:

$$\Psi = C_{10}\left(I_1 - 3\right) + \frac{k_1}{2k_2}\sum_{i=4,6}\left\{\exp\left[k_2\left(\kappa I_1 + \left(1 - 3\kappa\right)I_i - 1\right)^2\right] - 1\right\} \tag{2}$$

where C_{10}, k_1, k_2, are material coefficients, whereas I_4 and I_6 are invariants measuring the square of the stretch along the direction of the fibers. The κ parameter describes the dispersion of types of collagen fibers and assumes the value in the range between 0 and 1/3. When $\kappa = 0$ the fibers are ideally positioned in relation to each other, whereas when $\kappa = 1/3$, the fibers are positioned at random, creating the material with isotropic properties [1].

3. Material parameters of the constitutive models

The diversity, as far as the degree of simplification is concerned, of the available constitutive models creates the need to search for material parameters of each of them. This – in turn – creates the need to engage in a large-scale study of the mechanical properties of the tissues that build up blood vessels. The biggest obstacle is the material under investigation itself due to problems with its extraction (human tissue) as well as its characteristics. This is soft tissue of small size, which creates problems related to taking properly sized samples and building the adequate grabbing tools to supplement the measuring machine. Despite that many researchers take on this topic and deliver new information. Examples of such work are Jankowska et al and Maher et al [7,8].

4. Study objectives

The main motivation to touch upon this topic was the desire to find the optimal constitutive model of the material that builds up the tissue of different types of blood vessels. They include: elastic artery, muscular artery, arteriole and capillary. Moreover it was important to find effective material parameters that would make it possible to implement the selected constitutive model in FEM software. The need for this kind of investigation is grounded in the desire to build a simulated quantitative model of the selected blood vessel in which a non-Newtonian fluid (blood) flows together with the introduction of nanoparticles carrying medication into this fluid. This work includes the overview of the constitutive models of the blood vessel material that are currently being developed, together with the overview of experimental research of the properties of these materials geared towards calibration of the selected models that sufficiently replicate their behaviour. An informed choice of a given model will be the basis for using it in the analyses of the interaction between the blood vessel and nanoparticles.

6. References

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