MODELING OF FLUID SHEAR STRESS ON SMOOTH MUSCLE CELLS IN COMMON CAROTID ARTERY MEDIA

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Introduction

Vascular smooth muscle cells (VSMCs) are exposed to interstitial fluid flow induced shear stress. The alterations in shear stress may result in abnormal VSMC phenotypic modulation which are associated with atherosclerotic plaque formation [1].
Understanding interstitial fluid flow and shear stress on VSMCs in common carotid artery (CCA) has a key role in preventive strategies for atherosclerosis.
To develop an appropriate model to describe the shear stress distribution on VSMCs, the components of the media tissue are taken into consideration since their deformational behavior directly affects the hydraulic permeability of the extracellular matrix around VSMCs.
In this work, a lamellar unit (LU) of arterial media consisting of elastic lamellae (EL), VSMCs and interlamellar extracellular matrix (ECM) is developed and numerical methods are used to compute interstitial fluid flux through LU and flow induced shear stress on VSMCs in FEBio [2].

Methods

Figure 1 shows the representative volume element model of LU. Each different colored layer represents the components of LU. The geometry is constructed by considering the volume fraction of components.
A biphasic anisotropic fiber-reinforced constitutive model for ECM, biphasic neo-Hookean constitutive model for EL and solid neo-Hookean constitutive model for VSMC are employed. A pressure gradient in radial direction and a tensile stress in circumferential direction of LU are applied to have an appropriate circumferential stress-strain response of media layer.
The effect of age on shear stress on VSMCs is also investigated. Aging is represented by the change in the volume fractions of components and an increase in their elastic moduli.

Results

Figure 2 illustrates how LU deforms with increasing transmural pressure difference and tensile stress in physiological range.

Discussion

Both applied fluid pressure and tensile stress results in nonlinear deformation behaviour. While LU is stretched in circumferential direction, it is compressed in radial direction. The permeability through the radial thickness of the unit is changed depending on the radial compression. As a result, the interstitial fluid flow intensity and shear stress amount on VSMC are changed with pressure. Furthermore, it is observed that aging results in alterations in shear stress.

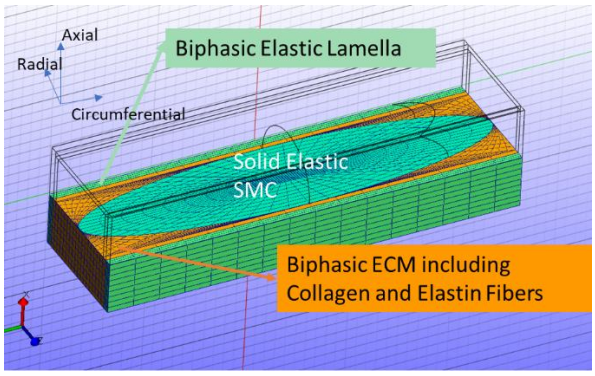

Figure 1: The meshed geometry of lamellar unit of human CCA media.

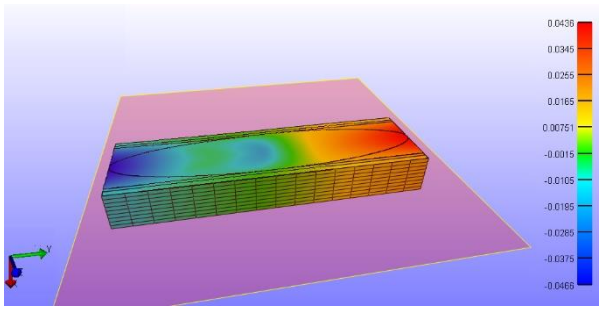

Figure 2: The deformation of LU in circumferential direction.

References

1. Qiu et al, J R Soc Interface, 11: 20130852, 2014.
2. Maas et al, J Biomech Eng, 134:011005-011005, 2012.