Active Response of Smooth Muscle and Arterial Tissue to Stenting

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Abstract

In restenosis, alterations in the bio-chemo-mechanical arterial environment post stent implantation results in the proliferation of smooth muscle cells and collagen extracellular matrix (CECM) remodelling [1, 2]. In the current study, a material model was applied to a single smooth muscle cell embedded in CECM and an unstented artery to examine SF development and distribution to test the hypothesis that increased arterial stiffness results in SF remodelling. We clearly demonstrate that the stiffness of the CECM influences hoop fibre activation level. This study provides insight into cell biomechanical response during restenosis and stenting.

1. Introduction

Current computational approaches to modelling cells in arteries treat the arterial wall as a passive hyperelastic anisotropic material with no active SF remodelling [3]. A user defined material (UMAT) is implemented as a user-subroutine in ABAQUS which incorporated active SF contractility, alignment and distribution of fibres initiated by bio-chemo-mechanical signals, and a passive anisotropic hyperelastic model for the arterial wall [4].

2. Materials and Methods

SF formation and tension dependent dissociation is captured using a first order kinetic equation:

$$\frac{d\eta}{dt} = [1-\eta]\frac{Ck_f}{\theta} - \left[1-\frac{\sigma}{\sigma_0}\right]\eta\frac{k_b}{\theta}$$

where η is the dimensionless activation level of a SF bundle and C is an exponentially decaying activation signal, k_f and k_b are the forward and backward reaction rate constants [4].

The contractile response of the bundles is modelled using the following Hill-like equation:

$$\frac{\sigma}{\sigma_0} = 1 + \frac{k_v}{\eta}\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}; -\frac{\eta}{k_v} \le \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \le 0$$

where the parameter k_v controls the slope of the tension velocity relationship during SF contraction [4].

2.1. Parametric Study

The UMAT is applied to a unit cube in Abaqus (RI, USA) representing a single smooth muscle cell embedded in CECM to examine the effects of varying the Young's Modulus of the surrounding CECM and k_v on the SF contraction.

2.2. Arterial Study

An axisymmetric artery is subjected to physiologically relevant loadings for diastole to evaluate hoop and axial SF activation levels for a range of values for the Young's Modulus of the CECM.

3. Results

3.1. Parametric Study

The unit cube underwent volumetric deformation only. Increasing k_v resulted in a significant increase in the contraction length. At K = ~35kPa both η and d/L converged to ~1 for every value of k_v (Fig 1).

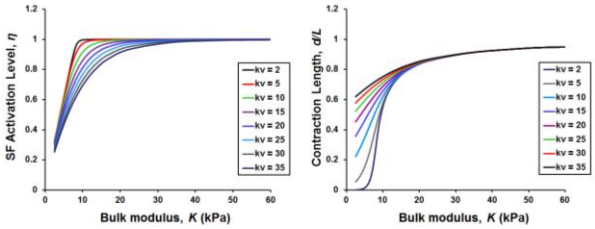

Fig 1: Contraction of cube geometry showing the change in SF activation level (η) and cube contraction length (d/L) as a function of the passive bulk modulus (K) for a range of values of k_v.

3.2. Arterial Study

The axial SF activation level remained unchanged. For stiffness's greater than ~200 kPa, hoop fibre activation level remains unchanged for the simulation. For lower stiffness's, hoop fibre dissociation is predicted during diastole (Fig 2).

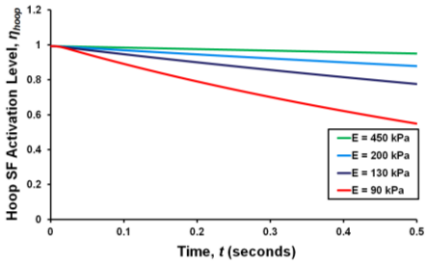

Fig 2: Change in SF activation level in the hoop direction (η_{hoop}) during diastole as a function of passive arterial stiffness. Pressure = 120mmHg at t = 0s and pressure = 80mmHg at t = 0.5s.

4. Discussion

An increase in arterial stiffness can occur due to atherosclerosis and stent implantation. This increased stiffness affects the hoop SF dissociation demonstrating a link between CECM stiffness and SF activation level.

5. References

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