A 3-Dimensional Multiphase Smooth Muscle Cell Model Exhibiting Anisotropy & Viscoelasticity

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Abstract

Smooth Muscle Cells (SMCs) constitute the major cells in the media layer of arteries and vessels. During biological processes, SMCs adapt their structure, dimension, and shape in response to mechanical and biochemical stimuli, thereby maintaining vascular tone to homeostatic levels [1]. The abnormal contractility of SMCs is associated with the development of many diseases such as hypertension and aneurysms. It is therefore essential to better understand the biomechanics of SMC dilation in health and disease.

In the present study, we examine the mechanical behavior of SMC when subjected to uniaxial tension tests, through Finite Element (FE) simulations. In general, vascular SMCs are spindle-shaped and have a single centrally located nucleus. The SMC intercellular space is a complex network comprising the actin and intermediate filaments that play a dominant role in the tensile properties of the cell [2]. Besides, it has also been reported that SCM exhibits hysteresis phenomena when subjected to stretch and release cycles [3]. Provided that, we present a 3-Dimensional multiphase SMC model, that encompasses the nucleus and cytoplasm surrounded by the cell membrane, as shown in **Figure 1**. The constitutive behavior of each phase is described through a strain energy function. The cell membrane and nucleus are treated as hyperelastic solids, whereas the cytoplasm is modelled as a transversally isotropic viscoelastic material incorporating one fiber family since. The model parameters are estimated by fitting the results of our simulations with previous experimental studies.

The cell is subjected to uniaxial tensile tests under different loading conditions including loading under constant velocity and loading/unloading process. In the latter case, large hysteresis phenomena are observed in the strain-stress curve obtained by our simulations, depicted in **Figure 2.** Those phenomena have been also reported experimentally [3]. In addition, we examine the dynamics of SMC for different fiber distributions and alignments. Our simulations indicate that the orientation and distribution of the filaments affect extensively the tensile properties of the cell.

Future directions

Many studies indicate that the intracellular calcium concentration determines the stiffness of SMC through an active contractile apparatus [4]. To this end, we want to introduce an active contribution to our current framework that will account for the calcium-activated response of SMCs.

Figures

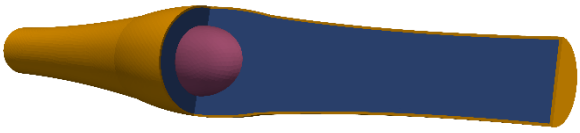

Figure 1: Geometry of the three-dimensional SMC model including the cell membrane, cytoplasm and nucleus depicted with yellow, blue, and purple color, respectfully.

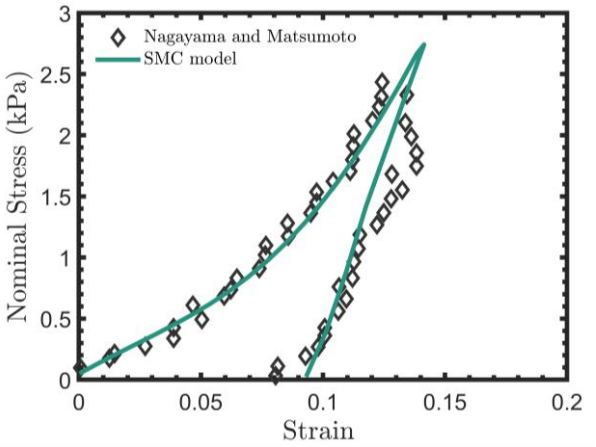

Figure 2: Comparison of the stress-strain curve obtained by our simulation with the experimental study [3] *for a load/unload cycle tensile test.*

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References

[1] D. Ingber et al., *J. Biomech.*, 28:1471–1484, 1995.

[2] K. Nagayama & T. Matsumoto, *JSME INT J C-MECH SY*, 47:985–991, 2004.

[3] K. Nagayama and T. Matsumoto, *Am. J. Physiol. - Cell Physiol.*, 295:1569–1578, 2008.

[4] Y. Zhu *et al.*, *Front. Physiol.*, 10, 2019.

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