Fluid-Structure Interaction Studies of Coronary Artery Disease Biomechanics

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INTRODUCTION: Cardiovascular diseases are the leading cause of death worldwide. In the United States, coronary artery disease accounts for 1 in 7 cardiovascular deaths[1]. Cells in the blood and blood vessels are known to respond to alterations of the mechanical forces of their environment, such as blood flow-induced shear stress and tensile strain caused by the dilation and contraction of the blood vessel itself. Computational models of the coronary arteries are used to estimate these values that are implicated in the development of atherosclerosis. Here we describe the development of two Fluid-Structure Interaction studies of the left anterior descending portion of the coronary artery in COMSOL®.

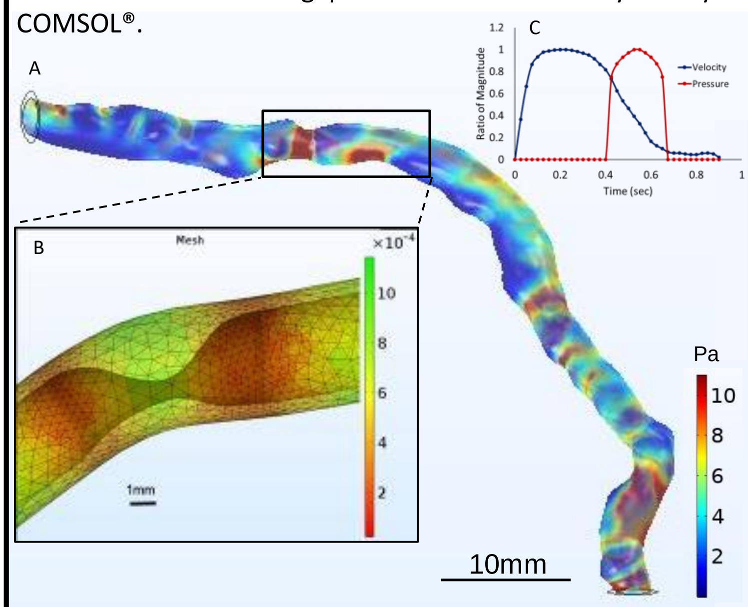

Figure 1. A. Mesoscopic model mesh with high spatial resolution (50µm average element size). B. Wall shear stress along a normal, 7.56cm long coronary artery (166µm average element size). C. Inlet velocity and cardiac squeezing pressure waveforms.

COMPUTATIONAL METHODS: Blood flow will be treated as a Newtonian fluid and the laminar flow is calculated according to the Navier Stokes Equations for incompressible fluids. Inlet waveforms are shown in Figure 1c. Patient-specific geometries were created using CTA data. A hyperelastic, 5-parameter Mooney-Rivlin material model was used in the solid domain, therefore the Nonlinear Structural Materials module was used. Healthy sections of artery were given material properties mimicking healthy arterial media and the stenosed section of artery were given properties mimicking a fibrous plaque [Table 1][2].

	C_{10} (kPa)	C_{01} (kPa)	C_{11} (kPa)	C_{20} (kPa)	C_{02} (kPa)
Media	9.26	3.50	1183.00	305.46	504.50
Fibrous Plaque	28.49	8.63	56.75	150.48	2721.00

Table 1. 5-parameter Mooney-Rivlin constants[2].

RESULTS: We developed 2 models of the coronary artery. The first is a 19mm long meso-scale FSI model of a diseased coronary artery containing a 70% stenosis. The second is a 7.56cm macro-scale FSI model of a normal coronary artery.

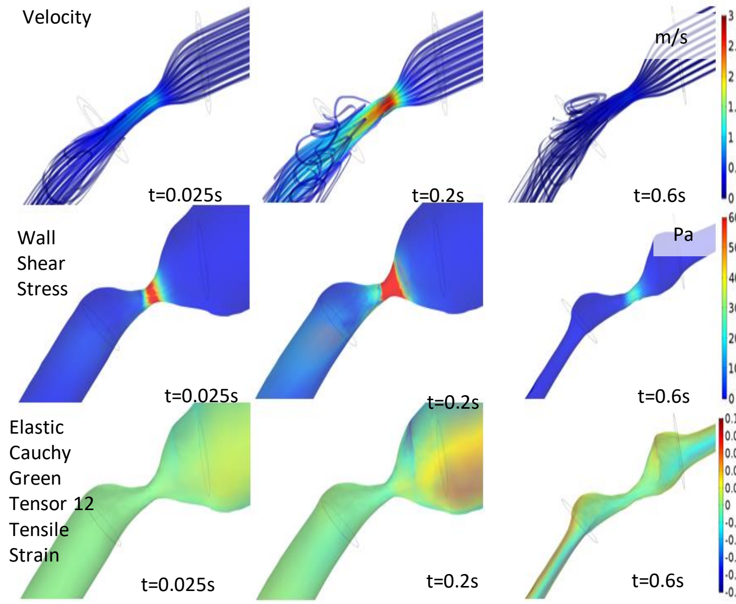

Figure 2. Flow parameters of the stenosis model.

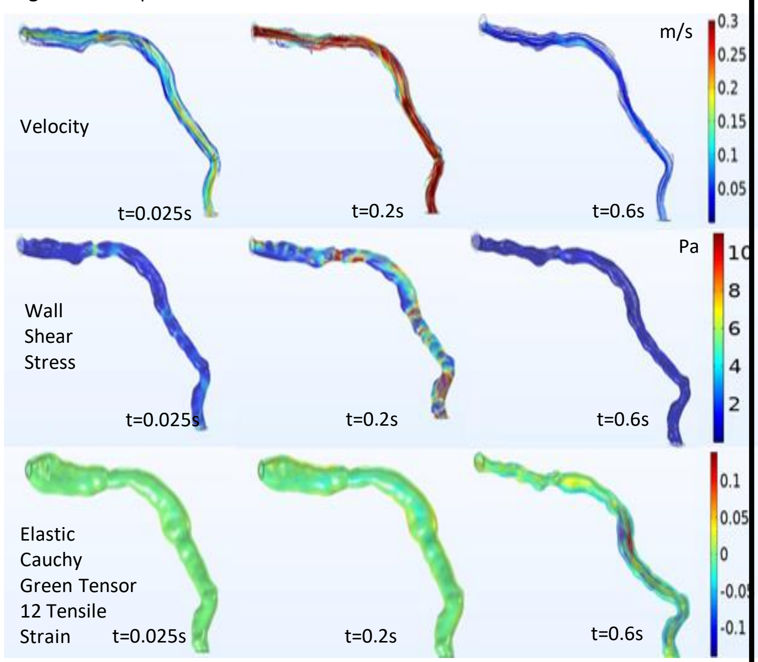

Figure 3. Flow parameters of the normal model.

CONCLUSIONS: Patient-specific models of coronary arteries can be used to determine wall shear stress and wall tensile strain, which are not readily available during clinical diagnostics. In the future, this data may be used to identify areas of vulnerability in the arterial wall.

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2. Teng et. al., "The influence of constitutive law choice used to characterise atherosclerotic tissue material properties on computing stress values in human carotid plaques", JBioMech, 48, pp. 3912-3921, 2015