Biofluid-Structural Interaction in Abdominal Aortic Aneurysm for Predicting Timeline to Rupture: The Effect of Hypertension and Aorta Wall Material Properties

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Introduction: An abdominal aortic aneurysm (AAA) is a bulge formed in the large blood vessels that supply blood to the abdomen, pelvis, and legs. A fluid structure interaction model was developed in a 3D aortic aneurysm model, which was constructed from an abdominal CT scan image (Fig.1). Combining medical imaging and computational fluid dynamics (CFD) in a time dependent study allowed the determination of wall stress, deformation, and fluid flow dynamic over a period of time. The model estimated the time to rupture based on the effects of hypertensive blood pressure and degradation of the diseased aortic wall mechanical properties.

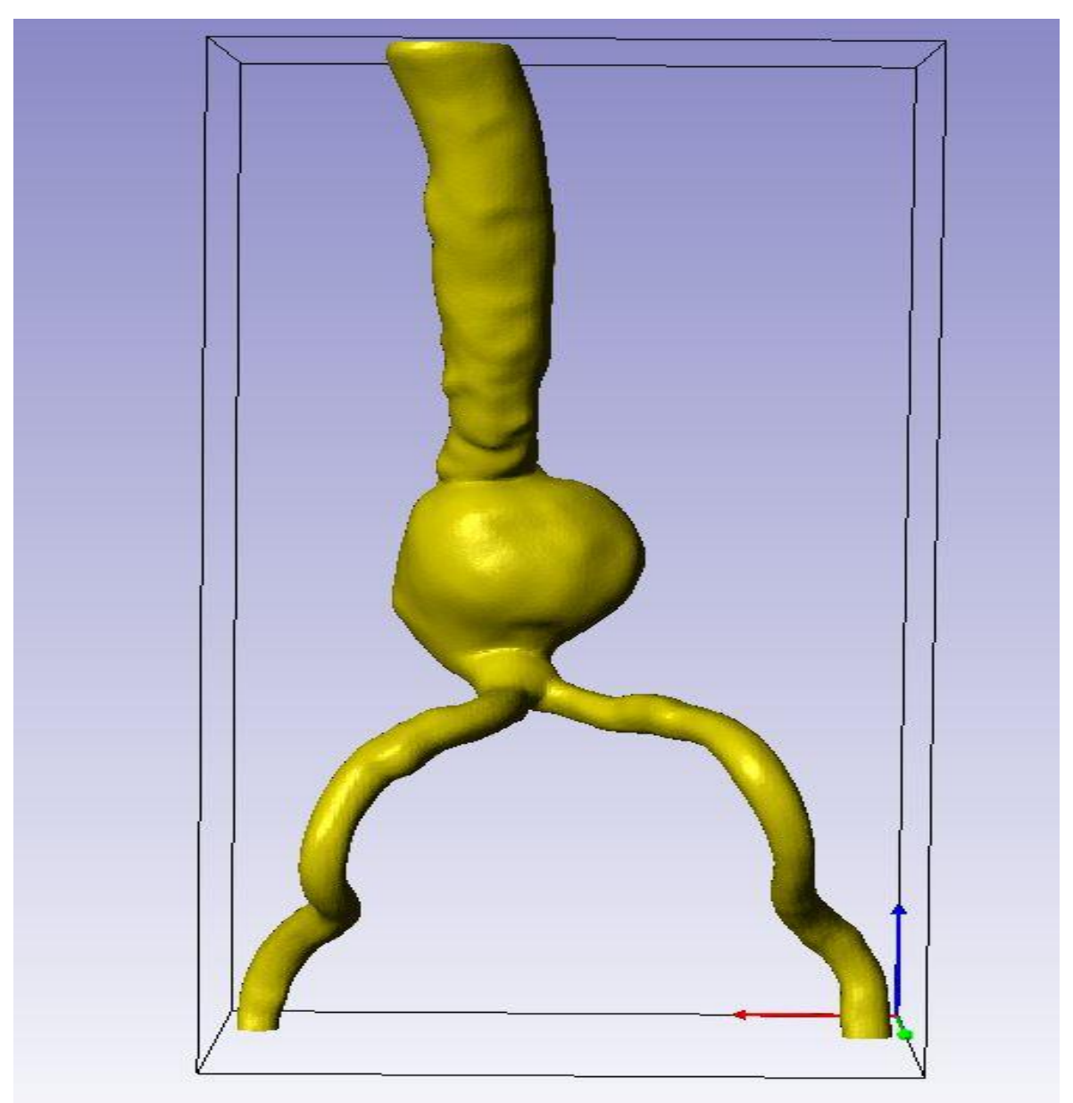

Figure 1. Sample Model of Abdominal Aortic Aneurysm

Computational Methods: The blood flow was assumed to be laminar Newtonian, viscous and incompressible. The Navier–Stokes equations in Arbitrary Lagrangian–Eulerian (ALE) formulation coupled with solid-mechanics equations for fluid interaction in the aorta wall were used as the governing equations as follows (Fig.2):

$$\rho \frac{\partial \mathbf{u}}{\partial t}_{fluid} + \rho\left(\mathbf{u}_{fluid} \cdot \nabla\right)\mathbf{u}_{fluid} =$$

$$\nabla.[-pI + \mu\left(\nabla \mathbf{u}_{fluid} + (\nabla \mathbf{u}_{fluid})^{T}\right)] + \mathrm{F}$$

$$\rho \nabla \cdot \mathbf{u}_{fluid} = 0$$

$$\rho \frac{\partial^2 \mathbf{u}}{\partial^2 t}_{solid} - \nabla.\sigma = F_v$$

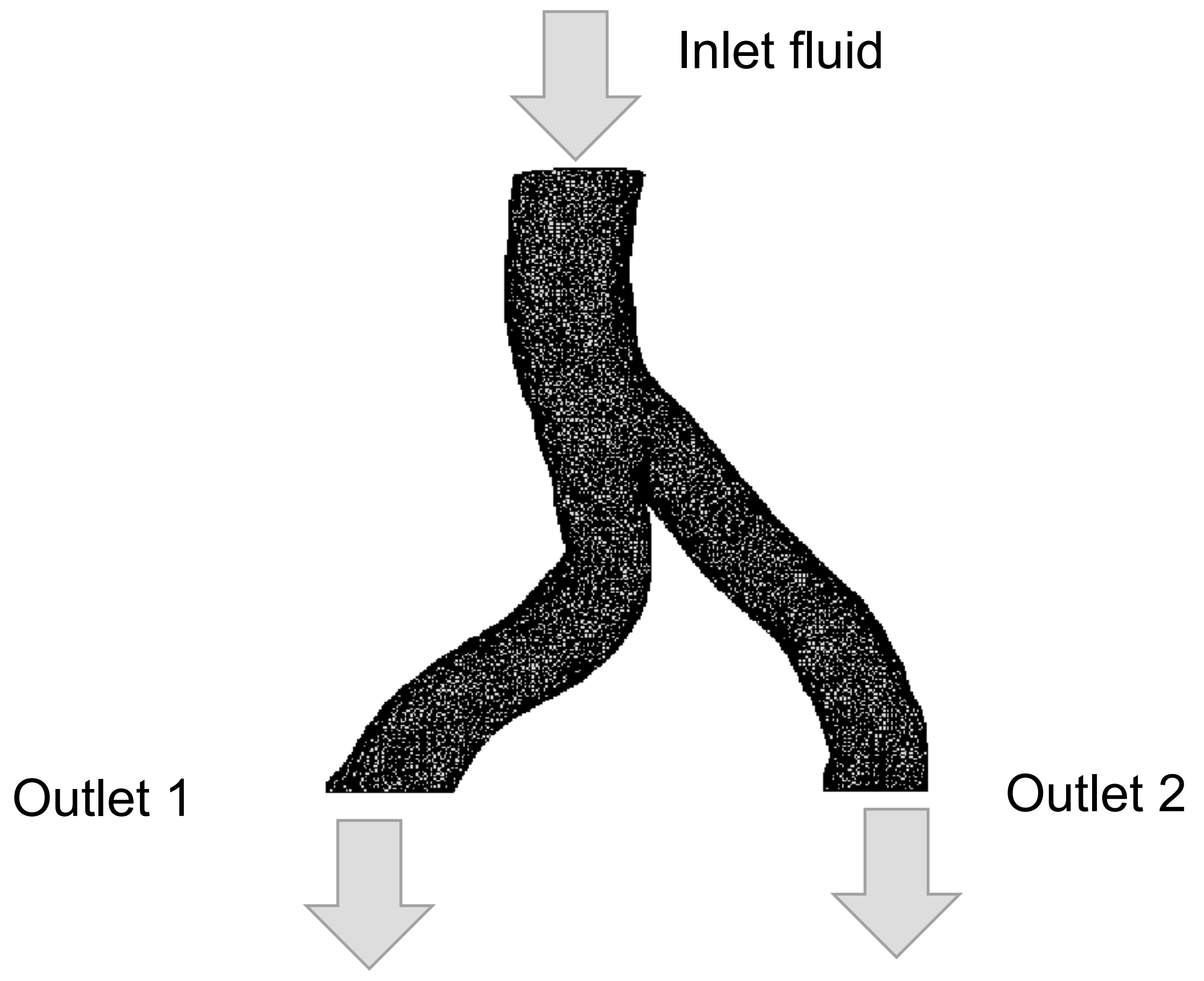

Figure 2. Boundary Condition for AAA Model

Results:

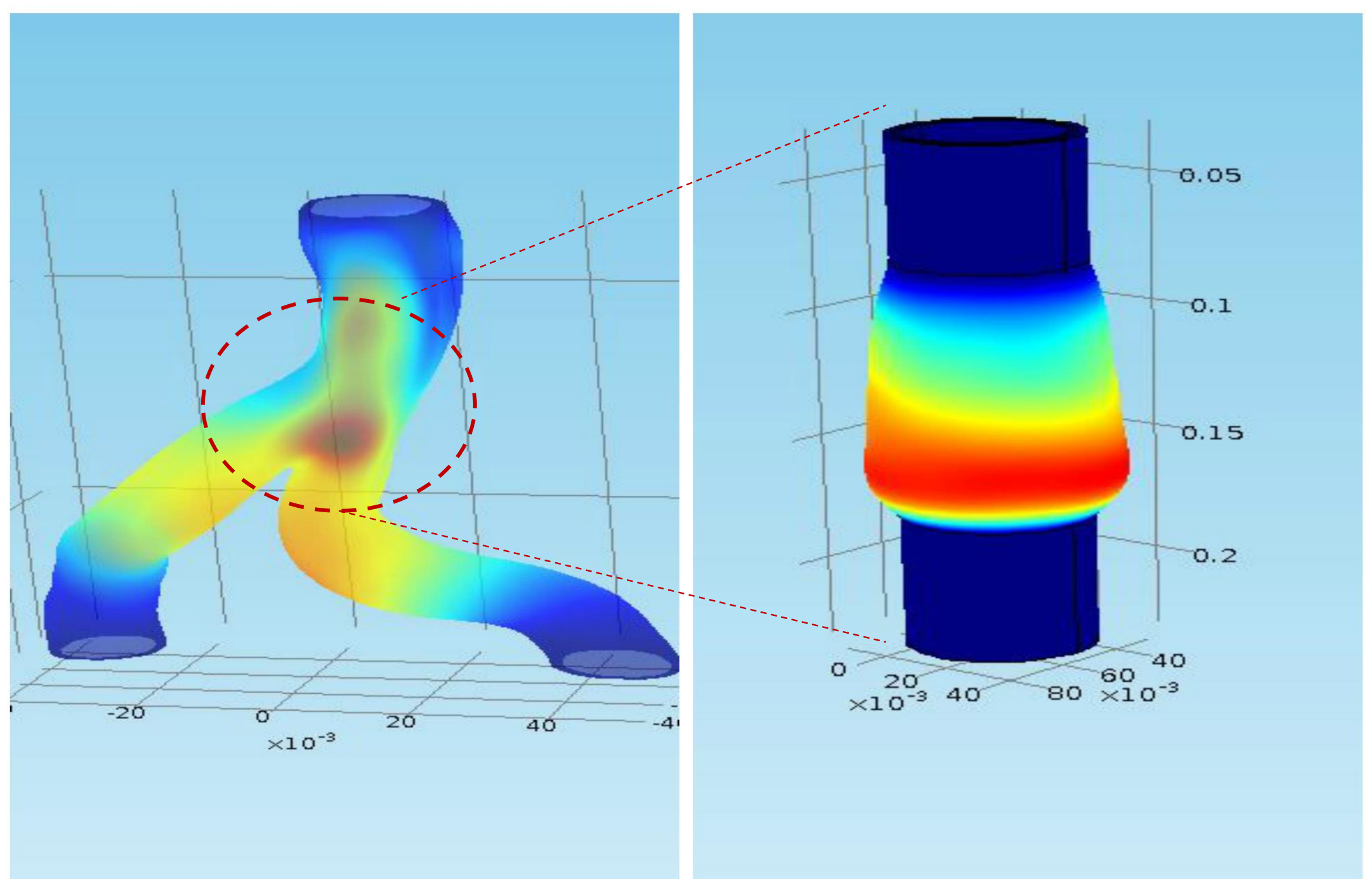

Figure 3. Displacement in actual and simplified aorta model

Conclusion: Fig.3 displays the initial displacement that occurs as the diseased aortic wall material properties begin to degrade. As the aortic wall material properties begin to degrade there is a decrease in Young's modulus (Fig.4) which increases the wall deformation as shown in Fig.5. When high blood pressure was simulated in the diseased aorta model, the vortex in the in the aneurysm produced a pressure gradient that acted on the aorta wall which further contributes to increased deformation in the aneurysm. Fig 5 presents the initial deformation that takes place in a diseased aorta wall over a small period of time. The analysis can be extended further to an increased period of time to predict the timeline for aneurysm to rupture.

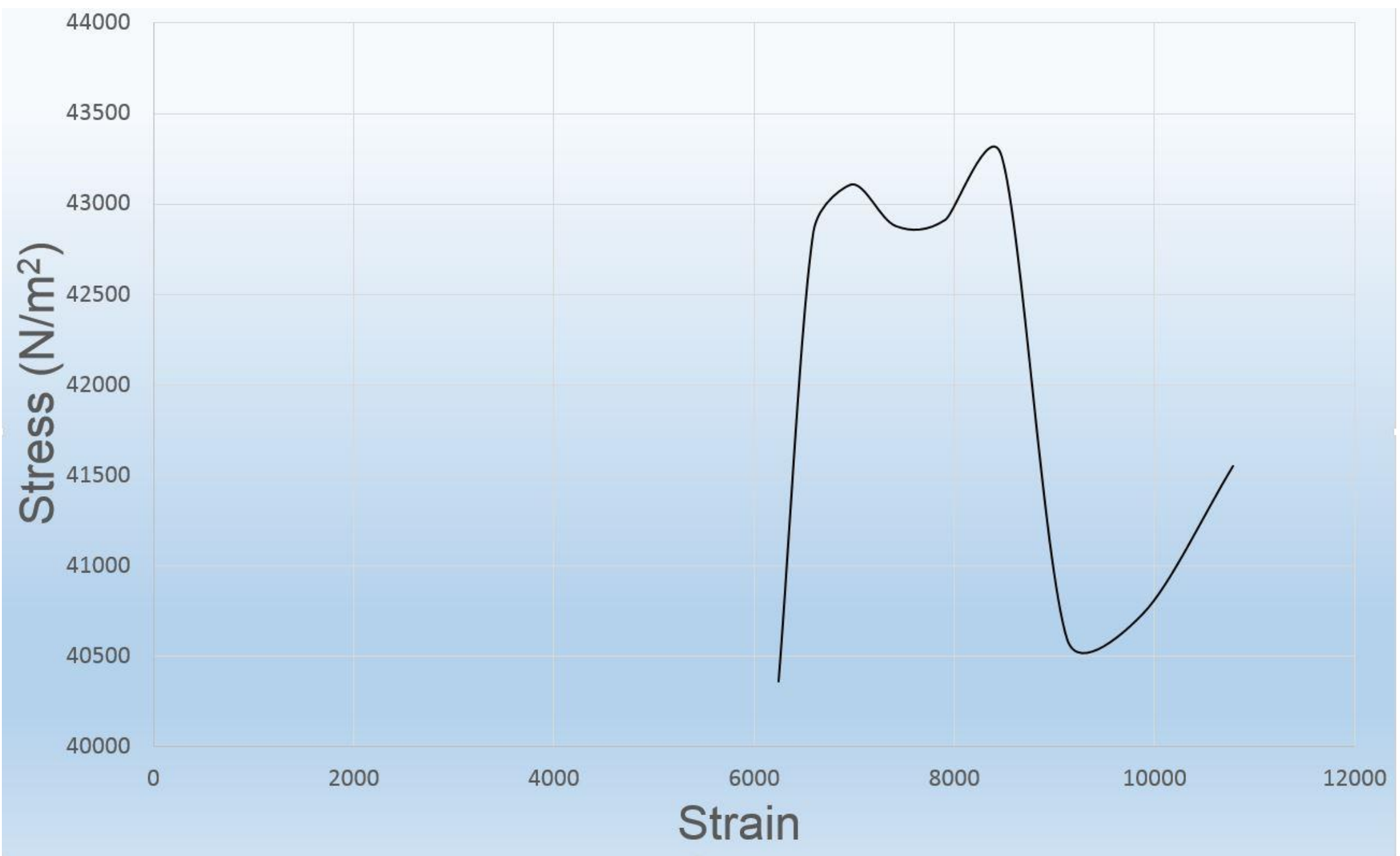

Figure 4. Stress vs. Strain

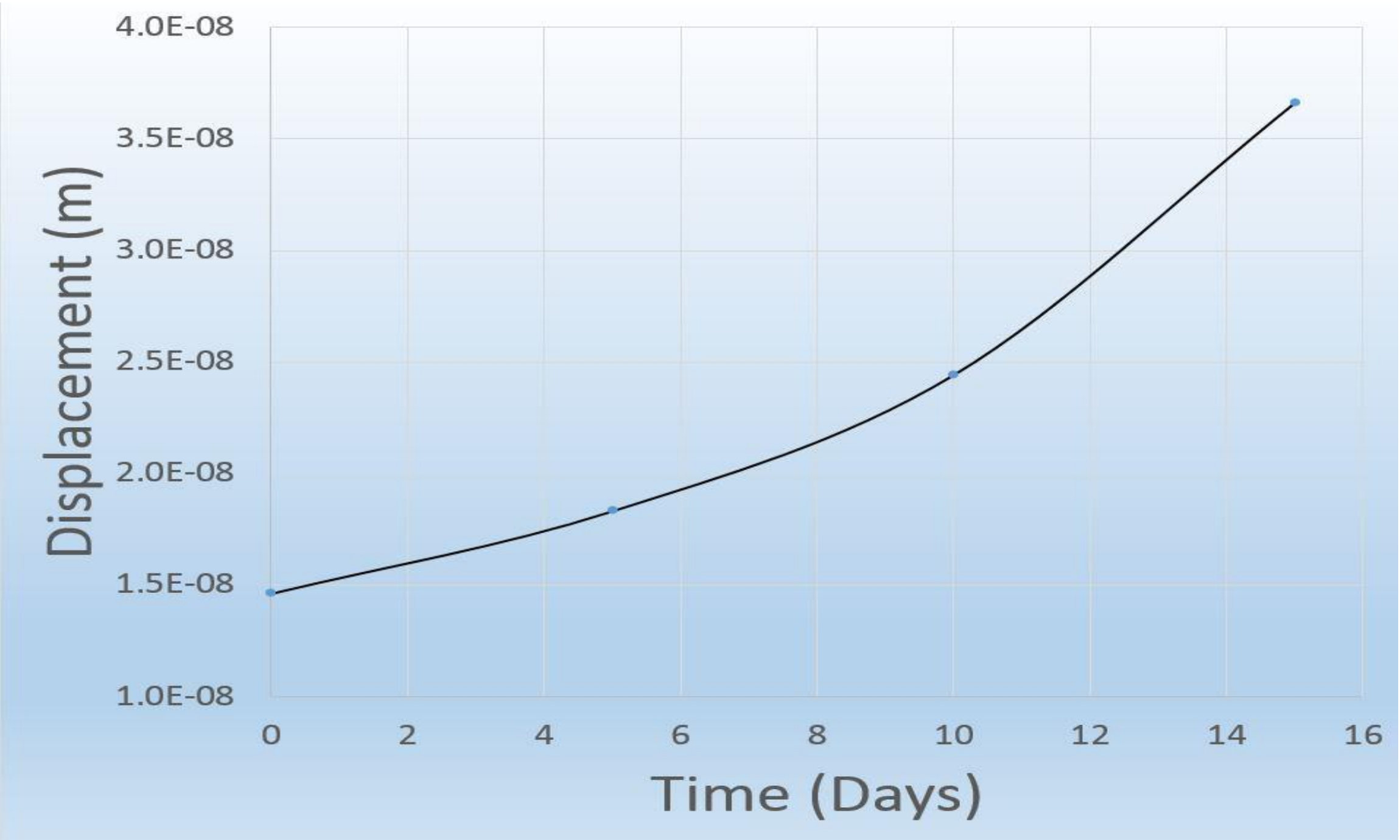

Figure 5. Time vs. Displacement

References:

1. Gao, F., et al., Fluid structure interaction simulation in three-layered aortic aneurysm model under pulsatile flow: comparison of wrapping and stenting. J Biomech, 2013. 46(7): p. 1335-42.

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