Assessment of fluid wall shear stress and vessel wall stress in an ‘ideal’ atherosclerotic plaque model

K. DUMONT, P. IMPELLIZER, J. RICOTTA, Y. ALEMU and D. BLUESTEIN

†Department of Biomedical Engineering, Biofluids Laboratory, Stony Brook University, Stony Brook, NY, USA
‡Department of Surgery, Stony Brook University Hospital, Stony Brook, NY, USA

1. Introduction

Plaque rupture is believed to be related to mechanical forces, various cell activities, chemical environment, and vessel surface conditions. The mechanism causing plaque rupture is not fully understood (Tang et al. 2004). To better understand the development of an atherosclerotic plaque an ideal straight tube blood vessel will be studied with a fluid-structure interaction numerical model. In a later phase a three-dimensional (3D) CT-based computational model with plaque structures will help to identify critical flow and stress/strain conditions which may be related to plaque rupture.

The numerical model will be used to study abdominal aneurysms. Surgical intervention to treat abdominal aortic aneurysm is appropriate when cumulative risk for aneurysm rupture exceeds risk for repair, within the context of overall life expectancy (Fillinger and Marra 2003). The model can help the estimation of rupture risk.

2. Methods

Vessel wall stress and fluid shear stress will be assessed in (i) healthy “straight tube” blood vessel, (ii) stenotic blood vessel (80% of area surface reduction), (iii) stenotic blood vessel with lipid core and (iv) stenotic blood vessel with lipid core and embedded calcification spots. The finite element solver ABAQUS is for the calculation of the vessel wall stresses. A visco-elastic material model is used to model blood vessel wall properties. The lipid core properties vary depending on the amount of calcification in the plaque. Fluid flow is calculated with Fluent and assumed to be laminar. Boundary conditions for the blood flow are based on ultrasound and/or pressure measurements.

3. Results

The results provide not only fluid shear stress but furthermore blood vessel wall stresses. Although high vessel wall stress is probably responsible for the failure of a vulnerable plaque, it is interesting to monitor both values during the progression and/or regression of the plaque formation.

Figure 2 shows preliminary “rigid wall” results of WSS in a reconstructed model based on CT images. Estimation of residence time in the aneurysm and

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Figure 1. Geometry of blood vessel lumen and plaque.

Figure 2. 3D reconstruction of an abdominal aneurysm.
downstream the stenosis, and platelet shear stress activation calculated with particle tracking in the blood flow may allow to predict thrombus formation.

4. Discussion and Conclusion

The model could help in understanding the progression process of a vulnerable plaque and could help determining the critical point in the pathologic process of aortic aneurysms.

5. Future Work and Goals

Future work will include the FSI study of abdominal aneurysms. Furthermore turbulence of the blood flow through severe stenotic vessels will be calculated with a k-omega turbulence model.

References

