THE 5^{TH} ASIAN COMPUTATIONAL FLUID DYNAMICS
BUSAN, KOREA, OCTOBER 27~30, 2003

Intra-luminal Thrombus Reduces Stress in the Aneurysm Wall: Fluid-Structure Interaction in Pulsatile Flow

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Abstract

Using computational fluid dynamics with the fluid-structure interaction, structural effects of intra-luminal thrombus were determined in thrombosed axisymmetric abdominal aorta aneurysm (AAA) models under pulsatile flow. Four different models, varying dilatations of the aneurysm and Young's moduli of intra-luminal thrombus, were defined. Compared with unthrombosed AAA models, both von Mises stress and radial displacements in the aneurysm wall significantly decreased. Stiffer intra-luminal thrombus reduced von Mises stress in the aneurysm wall. The present study supported that intra-luminal thrombus might reduce wall stress in the aneurysm.

Keyword: *Aneurysm, Intra-luminal Thrombus, Fluid-Structure Interaction, Structural Effects*

1. Introduction

Aneurysm is defined as a focal dilatation of a blood vessel. Abdominal aortic aneurysms (AAAs) are among the most lethal phenomena in the elderly population, occurring approximately 2% of the population with rapidly growing incidences. Once AAA develops, tension in the arterial wall increases, and thus it exhibits abnormal deformations with the increased possibility of its rupture.

Even though numerous fluid dynamic studies were performed to determine the effect of wall shear in the aneurysm, the rupture of the aneurysm could not be explained. Many finite element studies were performed to investigate the structural characteristics in the aneurysm relating with the rupture of AAA. Vorp et al [1] performed stress analysis to investigate the effect of the size and the asymmetry of the aneurysm on the wall stress. Inzoli et al [2] applied the finite element method and showed that thick thrombus decreased the stress in the arterial wall, reducing the lumen of AAA.

Thrombus in the aneurysm affects the stress distribution in the aneurysm wall. Recently, Mower et al [3] performed the finite element analysis and reported that the intra-luminal thrombus could significantly reduce AAA wall stress. The possibility of the rupture of AAA might be better explained with fluid-structure interactions. Kwon and Kim [4] performed a computational study on AAA models using fluid-structure interactions under pulsatile flow conditions. However, their studies neglected the existence of intra-luminal thrombus in the aneurysm.

Therefore, the aim of the present study is to determine the effect of the intra-luminal thrombus on both the structural characteristics and the blood flow in AAA under pulsatile flow conditions using fluid-structure interactions.

2. Methods

Fig. 1 shows the geometry of axisymmetric AAAs for the present study. Four different models of AAAs are listed in Table 1, varying the size of aneurysm and Young's modulus of intra-luminal thrombus. For all models, half of the aneurysm was filled with intra-luminal thrombus. Longitudinal locations of AAA were represented by the ratio with respect to the diameter of the undeformed artery. Wall thickness in the aneurysm wall was smoothly reduced so as to be minimal at 0D and maximal at ±2D.

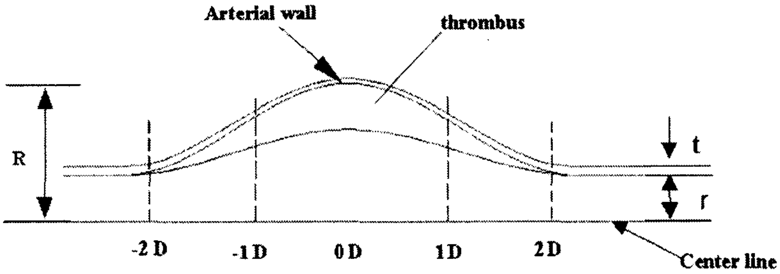

Fig. 1. Geometry of thrombosed axisymmetric AAAs

Table 1. Aneurysm models

	Radius of the undeformed artery, r (mm)	Radius of the maximum dilatation, R (mm)	Arterial wall thickness, t (mm)	Young's modulus of thrombus, E [3] (MPa)
Model 1	7.5	15.0	1.5	0.1
Model 2	7.5	15.0	1.5	1.0
Model 3	7.5	22.5	1.5	0.1
Model 4	7.5	22.5	1.5	1.0

The pressure difference between the proximal and distal ends was given as the boundary condition, as shown in Fig. 2. The outlet pressure was set to 99 mmHg, and no-slip condition was applied at the inner wall of the artery. Mean and peak Reynolds numbers at the inlet were 830 and 2,580 respectively. Both inlet and outlet were fixed in the axial direction for the structural constraint as a symmetry condition so that only radial deformations were allowed at both locations. The artery was assumed as a homogeneous isotropic material with Young's modulus of 1 MPa, and Poisson's ratio of 0.49. The density and the viscosity of the blood were assumed as 1,060 kg/m^3 and 0.035 Poise. The blood was also assumed as Newtonian fluid. The pressure-based finite-volume software, CFD-ACE was used to solve axisymmetric governing equations. Modified Navier-Stokes equations for moving-grid pulsatile flow were used in this study.

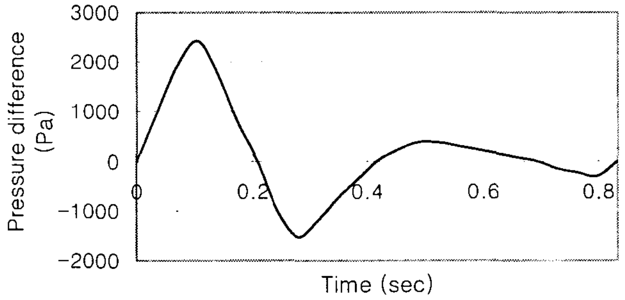

Fig. 2. Boundary conditions, given by pressure differences across both ends of the artery

3. Results

Fig. 3 represents von Mises stress distributions at peak systole for four models. It showed that von Mises stress in the aneurysm wall decreased for models with stiffer intra-luminal thrombus. For all models in the present study, the highest stress was found at the end of aneurysm. It was reported that for unthrombosed aneurysm, the maximum stress was found near 0D or ±1D in the aneurysm wall. This results supports that intra-luminal thrombus may absorb tension and reduce wall stress in AAA.

Fig. 4 represents radial displacements of the arterial wall at peak systole along the aneurysm for four models. Radial displacements of the arterial wall decreased for models of stiffer intra-luminal thrombus. For Model 3 and 4, at peak systole, the maximum radial displacement occurred at ±1D and ±1.8D, which are significantly small comparing with unthrombosed models of the same geometries.

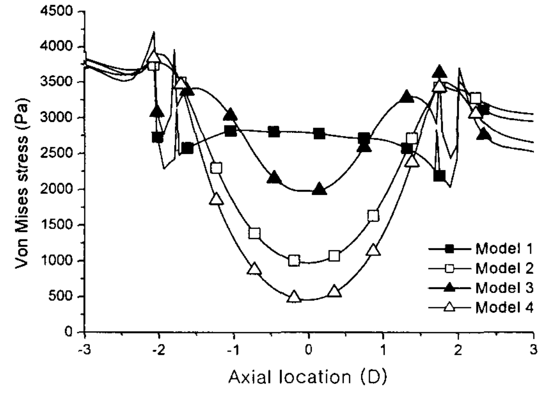

Fig. 3. Von Mises stresses of the arterial wall at peak systole

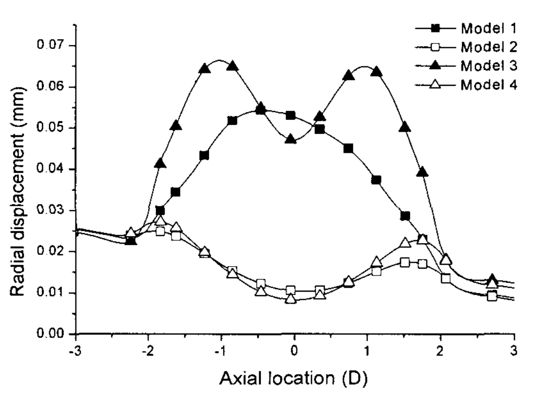

Fig. 4. Radial displacements along the aneurysm wall at peak systole

4. Conclusion

In the present study, structural effects of intra-luminal thrombus were determined in pulsatile flow for four different axisymmetric AAAs using fluid-structure interactions. From the present study, it was found that both von Mises stress and radial displacements decreased, comparing with unthrombosed AAA models. In addition, stiffer intra-luminal thrombus reduced von Mises stress in the aneurysm wall. Thus, intra-luminal thrombus formation might be viewed as a natural protective response against the rupture of aneurysm.

Acknowledgements

This work was partially supported by RRC program of MOST and KOSEF.

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