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FLUID STRUCTURE INTERACTION IN A CEREBRAL ANEURYSM MODEL USING THEIR OWN MECHANICAL PROPERTIES OBTAINED EXPERIMENTALLY

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SUMMARY

Cerebral aneurysms are thin walled and with different mechanical properties as an artery. The current investigation describes the fluid structure interaction (FSI) in a patient specific model of a cerebral aneurysm in the left ophthalmic carotid using their own mechanical properties of the aneurysm tissue obtained experimentally, previously.

Four FSI simulations were performed using the software ADINA. For the mechanical properties we have compared linear versus Mooney-Ryvlin hyperelastic material model and we have compare the FSI solution using complete coupling between the fluid and solid simulation versus the FSI solution with one direction coupling

INTRODUCTION

A cerebral aneurysm is an abnormal and localized dilation of an artery; this disease is normally found in the anterior and posterior regions of the circle of Willis. The aneurysm wall is composed of layered collagen. Wall strength is related to both collagen fiber strength and orientation.

Before rupture, the wall of cerebral aneurysm undergoes changes associated with remodeling of the aneurysm wall. Fluid wall shear stress (WSS) modulates endothelial cell remodelling via realignment and elongation, and the variation of WSS significantly affects the rates at which endothelial cells are remodeled.

This problem can be investigated using fluid structure interaction (FSI) simulations. However, few FSI investigations have been performed on patient specific aneurysms models. With the restriction of constant thickness, Valencia et al. have compared FSI with computational structural dynamics simulations. The difference in the maximum effective stress on the aneurysms was small, but the difference in the effective stress on the aneurysm fundus was large.

METHODS

In a parallel work of our group, we experimentally determinate the mechanical properties, rupture stretch ratio and breaking strength of this human cerebral aneurysm. The aneurysm tissue was obtained from surgical clipping and six samples were tested. The mechanical tests were performed in a micro tension machine. The experimental data were fit using ADINA following a five parameters Mooney-Rivlin hyperelastic model. Also an elastic modulus E for the tissue was determinate.

For the clinical examination of the cerebral aneurysm a three dimensional rotational Phillips Integris Allura angiograph was used, the images were obtained during a 180° rotation. The geometry was reconstructed and a 3D CAD geometry was obtained.

The flow was considered laminar and the blood non-Newtonian, the Carreau fluid model was selected to describe the rheological behavior of blood. A velocity profile obtained using flow measurements with pulsed Doppler ultrasound acquired from the right internal carotid artery in 36 patients with cerebral aneurysms, was used as inlet velocity. For the velocity profile at model inlet, we considered the Womersley solution for the velocity field variation in a pipe with the time and radial position. The pressure at model exit was adjusted to the normal pressure variation between 80 and 120 mmHg.

The wall thickness was different in the model, for the artery was 0.4 mm and for the aneurysm was 0.35 mm. The FSI model solves the momentum equation in the solid, the wall was considered as shell with hyperelastic properties adjusted by a Mooney-Ryvlin o elastic wall with a constant elastic modulus. The average equivalent elastic modulus obtained experimentally was E=1.86 MPa. The average rupture stretch ratio and breaking strength were 1.38 and 1.76 MPa.

The FSI model was implemented in the software ADINA. For the fluid we used Flow-Condition-Based-Interpolation tetrahedral elements. FCBI elements were used because they are stable for high Reynolds numbers. We used an iterative FSI coupling solution method. The finite element equations are assembled by calculating Jacobian matrices using Newton-Raphson iterations. We use complete coupling between the fluid and solid simulation and the FSI solution with one direction coupling.

RESULTS AND DISCUSSION

We have performed 4 FSI simulations considering, case 1 elastic and coupling complete, case 2: elastic and coupling one direction, case 3: Mooney-Rivlin and coupling complete and case 4: Mooney-Ryvlin and coupling one direction.

The figure 1 shows the effective stress on aneurysm surface, the maximum stress is on aneurysm body not in the fundus and it reaches 714 kPa, for the case 3.

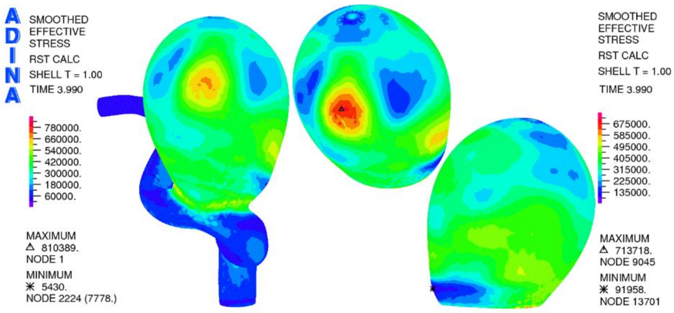

Figure 1: Smoothed effective stress on the aneurysm for the systolic time.

Table 1 shows the displacement, effective stress, pressure, WSS and velocity for the 4 FSI simulations. The hyperelastic model show differences with the elastic model, especially in the effective stress. The one direction coupling shows similar results compared using the same wall model (1 and 2; 3 and 4).

CONCLUSIONS

In this work we reported the first FSI calculation in a patient specific model of a cerebral aneurysm in the left ophthalmic carotid using their own mechanical properties of the aneurysm tissue and wall thickness obtained experimentally. The hyperelastic model predict larger maximum effective stress on aneurysm surface. The one direction coupling predicts similar results with a large spare in computational time.

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Table 1: Principal Results of 4 FSI simulation: 1: elastic and coupling complete, 2: elastic and coupling one direction, 3: Mooney-Rivlin and coupling complete, 4: Mooney-Ryvlin and coupling one direction.

FSI Simulation	Maximum displacement [mm]	Maximum effective stress [kPa]	Maximum Pressure [Pa]	Wall shear stress Control point [Pa]	Maximum Wall Shear Stress [Pa]	Maximum velocity Half plane [m/s]
1	4.4	461	23960	0.71	34	0.333
2	4.3	505	26916	0.57	39	0.269
3	4.1	714	25064	0.64	36	0.316
4	3.8	761	26916	0.57	39	0.269