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The Descending Aortic Aneurysm under Vascular Structure having Three-layered using FSI

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Summary

The aortic disease is 2nd place of the cause of death. If the thoracic part and the dissociation are matched, the aortic aneurysm exceeds 60 percent. The aneurysm decided based on the maximum diameter of the aneurysm from the image of which it takes a picture with CT or MRI etc. as such a diagnostic indicator. The appearance of disease, the development, and the rupture of the arterial hemangioma are thought that the hemodynamics such as intravasculars and vessel walls plays an important role [1,2]. Then, we simulated the aneurysm of descending aorta in consideration of the vessel wall of the three layered.

Introduction

The aneurysm of dissociation is classified into 3 + 1 types. Type I is that dissociation starts from ascending aorta, and dissociation cavity developed to abdominal aorta. Type II is that the dissociation starts from the ascending aorta, and the dissociation cavity is the circumscribed lingua one in the ascending aorta. And Type IIIa is that that restricts to aorta descendens though the dissociation starts from the aorta thoracica. Type IIIb is that the dissociation started from the aorta thoracica, and it developed from aorta descendens to the abdominal part of ureter. The aneurysm and the dissociation concerning the ascending aorta are symptoms among these that need operative in the emergency.

The aorta is made up of three layers: a tunica intima, a middle layer called the tunica media, and an outer layer the tunica adventitia (reference Fig.1).

We simulated the aneurysm of descending aorta in consideration of the vessel wall of the three layered.

Fluid Structure Interaction (FSI) [3]

The simulation is performed by means of a fluid-structure interaction approach. This technique allows us to study the aortic fluid-mechanics by accounting both for the fluid forces acting on the wall and the effects of the wall motion on the fluid dynamic field. Operatively, an ALE (Arbitrary Lagrangian Eulerian) algorithm is used that seeks, at each increment of the step, the convergence of the three blocks of equations, fluid (CFD), solid (CSD) and mesh movements (CMD), which must then converge altogether before a new step is initiated.

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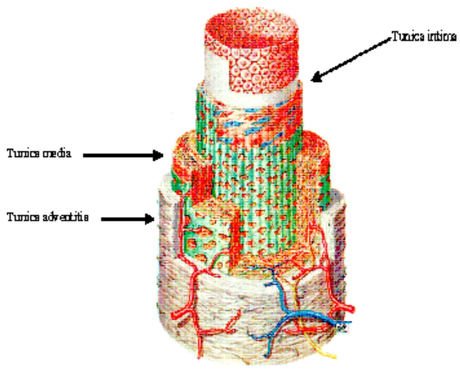

Fig. 1: Structure of Blood Vessel

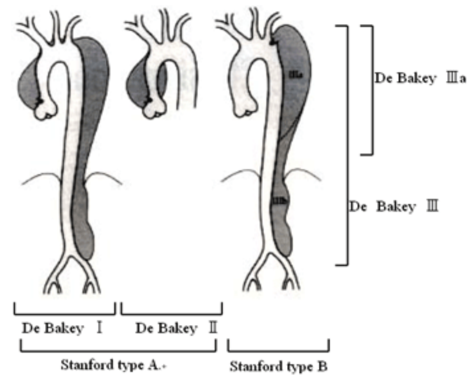

Fig. 2: Aneurysm

The equations governing the fluid (CFD) are:

$$\begin{array}{l} \rho \frac{\partial u}{\partial_i} + \rho u_{i,j} \cdot (u_j - \hat{u}_j) = \sigma_{ij,j} + \rho f_i \\ \frac{\partial \rho}{\partial t} + (\rho u_j)_{,j} = 0 \end{array} \quad \text{in } {}^{F}\Omega(t) \tag{1}$$

where u_i is the velocity, ρ is the fluid density, σ_{ij} is the stress, f_i is the body force at time t per unit mass, $\hat{u}$ is the mesh velocity at time t and ${}^{F}\Omega(t)$ is the moving spatial domain upon which the fluid is described. For a nearly incompressible fluid the first term of the second equation is equal to zero.

The equations governing the structural domain (CSD) are the momentum equation, the equilibrium condition and the constitutive equation, respectively:

$$\rho a_i = \sigma_{ij,j} + \rho f_i \text{ in } {}^{S}\Omega(t) \tag{2}$$

$$\sigma_{ij,j} n_j = t_i \text{ on } {}^{S}\Gamma(t) \tag{3}$$

$$\sigma_{ij} = D_{ijkl} \varepsilon_{kl} \text{ in } {}^{S}\Omega(t) \tag{4}$$

where a_i is the acceleration of a material point, ${}^{s}\Omega(t)$ is the structural domain at time t, n_j is the outward pointing normal on ${}^{s}\Gamma(t)$, t_i is the surface traction vector at time t, ${}^{s}\Gamma(t)$ is the boundary of the structural domain, D_{ijkl} is the lagrangian elasticity tensor, and ε_{kl} is the infinitesimal strain tensor.

The mesh is deformed (CMD) under the assumption that it behaves like an elastic medium described by the same equations used for the structural domain.

Simulation

We calculate two models. The first model is pipe model adding aneurysm. The sharp of aneurysm is that height is 0.04m and width changed to 0.06m (model name is MM), 0.08m (model name is M) and 0.1m (model name is ML). The diameter of the blood vessel is 0.03m. The thickness of the blood vessel was assumed to be

0.2% [4] of the vessel diameter. In the three-layered model, the average thickness ratio of intima/media/adventitia is set to 1/6/3. Fig. 3 is M model.

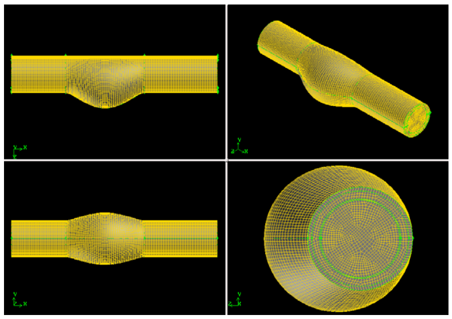

Fig. 3: Pipe Model

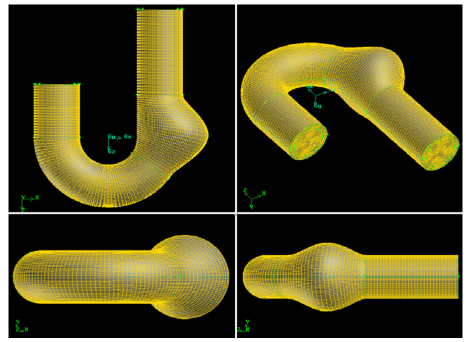

Fig. 4: Arch Model

And Fig. 4 is the second model (arch model). This arch model imitated the aorta having the aneurysm of M model.

The aortic wall is assumed to be an isotropic, linear, elastic solid with a density p = 1090 kg/m^3 and Poisson's ratio μ = 0.45. In Mosora's [5] experiments, 2MPa-6.5MPa was obtained for thoracic ascending aorta. The maximum E = 6.5MPa was chosen for the Young's modulus of one layer aorta wall. And we can obtain the Young's modulus of intima layer, media layer, and adventitia layer: E_i = 2.98MPa, E_m = 8.95MPa, E_a = 2.98MPa.

The fluid is Newtonian with a density of 1050 kg/m^3 and a viscosity of 0.0035 Pas. And Reynolds number is Re = 1000.

Result

Fig. 5 $\sim$ 7 is three-layered V.S. one-layered of intima, media and adventitia displacement. Fig. 8 is displacements that add the displacement of the each tunica to the displacement of wall. In Fig. 8, we understand that the displacement of the wall is the same. But in the vessel wall, there is a difference (three-layered is interface, one-layered is virtual interface). Fig. 9 $\sim$ 11 is compared with width of aneurysm and fixed height of aneurysm. The displacement is small when the width of aneurysm is large. Moreover, each peak is large in the direction of the entrance of the aneurysm. And each peaks is 1/4 of the width of the aneurysm in the direction of the entrance.

Fig. 12 and 13 are the contour of velocity and the contour of pressure of the cutting cross section in Y = 0 using the model that the aorta is assumed arch model having aneurysm to aorta descendens. In the contour of velocity, the exfoliation has happened near the exit of the bow. Moreover, the exfoliation has happened also

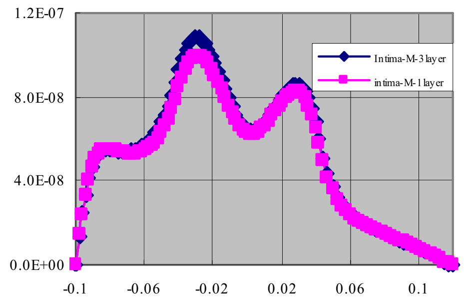

Fig. 5: three-layered V.S. one-layered -intima-

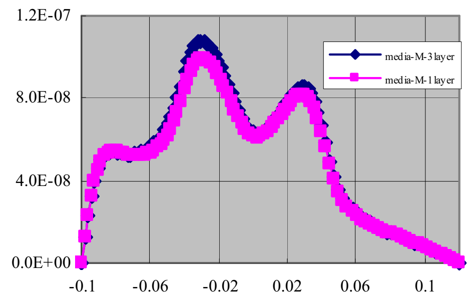

Fig. 6: three-layered V.S. one-layered -media-

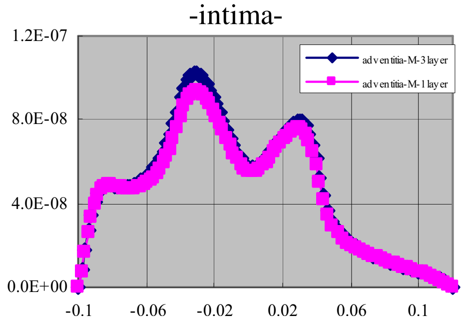

Fig. 7: three-layered V.S. one-layered -adventitia-

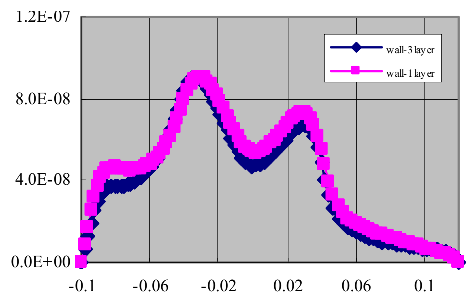

Fig. 8: displacement

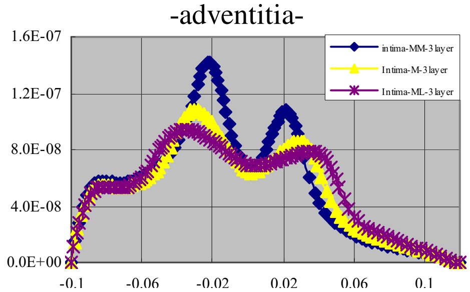

Fig. 9: Different of Pipe model width -intima-

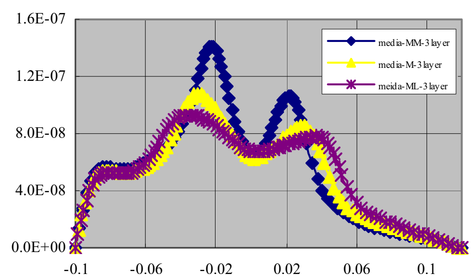

Fig. 10: Different of Pipe model width -intima-

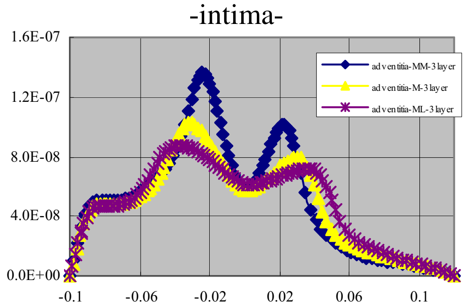

Fig. 11: Different of Pipe model width -adventitia-

at the entrance of the aneurysm. The highest at the velocity has gone out in the exit part of the aneurysm. In the pressure distribution, the upper part of the aneurysm is a maxima.

Conclusion

We simulated the aneurysm of descending aorta in consideration of the vessel wall of the three layered. The appearance of the inner wall is quite different while the appearance of outer wall doesn't change. The one layered and the three layered describe flow (pressure and velocity, etc.) unchanged clearly. In a tunica media, there is a stress concentration. In the future, we will simulate the unsteady or for model having dissociation.

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