INFLUENCE OF WALL DEFORMATION ON WALL SHEAR STRESS DISTRIBUTION OF INTRACRANIAL ARTERY

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INTRODUCTION

Over 90% of subarachnoid hemorrhages are caused by rupture of cerebral aneurysms. Although the risk of rupture is known to be less than 0.1%, aneurysms are usually operated if they are identified. On the other hand, the risk of postoperative sequelae is over 10% [1]. Thus it is important to predict risk factors of rupture of cerebral aneurysms in order to avoid unnecessary surgeries. Since it is reported that growth and rupture of aneurysms are associated with hemodynamic factors, the authors have been conducted a study to predict growth and rupture of cerebral aneurysms using numerical simulation. In this paper, numerical method for interaction between blood flow and arterial wall is developed. Results are compared with those of numerical simulations with rigid arterial wall. Especially, as WSS (wall shear stress) is an important factor for cerebrovascular disorders [2], influences of elastic arterial wall on WSS distribution are investigated.

COMPUTATIONAL METHOD

For fluid calculation with moving domains, DSD/SST (Deforming-Spatial-Domain / Stabilized Space-Time) method [3] is used to descretize both Navier-Stokes and the continuity equations. For structural calculation, FEM is used to descretize the equilibrium equation with the elastic constitutive law. Fluid and structural equations are iteratively solved by exchanging force and displacement at the boundaries.

COMPUTATIONAL MODEL

Three-dimensional geometry of the ICA (internal carotid artery) is extracted from CT (Computed Tomographic) angiography (see Figure 1). The arterial wall is assumed to be elastic body with thickness of 0.3 mm. The diameter of artery is about 4mm. Elastic coefficient of wall and Poisson's ratio are assumed to be 10MPa and 0.45 respectively. The inflow boundary condition is steady inflow and magnitude of velocity is assumed to be the same magnitude at the peak of systole. Pressure resistance, which corresponds to downstream resistance, is applied to the outlet boundary. The wall boundary conditions for fluid are non-slip. The inflow and outflow boundaries are fixed in structural calculation. The Reynolds number is about 600. Number of nodes is 29,643 and number of elements is 27,328. All calculations were performed on HITACHI SR8000.

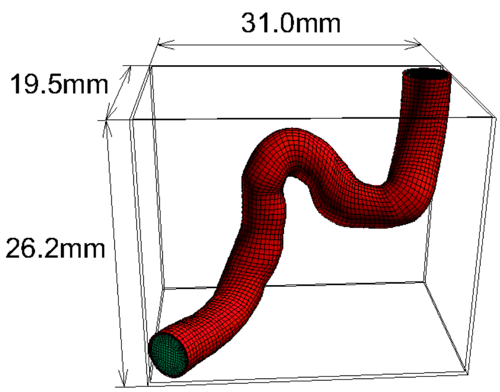


Figure 1. Computational model

RESULTS

Figure 2 shows the distribution of wall deformation. Color contour show scalar products of displacement vector of the wall and normal vector of the wall. The red part goes toward outside of wall while the blue part goes toward inside of wall. From distribution of area A, it is shown that wall moves in the direction perpendicular to screen. The maximum magnitude of deformation is about 1mm in the area A.

Figure 3 (a) shows WSS distribution of the case with compliant wall and Fig. 3 (b) shows that of the case with rigid wall. Significant difference of WSS distribution between two cases is shown in these figures. Figure 4 shows the flow velocity distribution in three cross sections indicated in Fig. 4 (g). Color contour show the axial flow velocity distribution perpendicular to the cross sections and the vector shows the velocity distribution in the cross sections. In cross sections A and B, direction of wall deformation is indicated by black arrow. At all areas where the WSS is high (area E, F, G, H, I), the velocity gradient near the arterial wall is significantly high. To see the section A, the velocity gradient around the area H is very high without wall deformation, and the velocity gradient around the area E becomes high with wall deformation. The reason is that the physical relationship between the area of high velocity gradient and the arterial wall changes due to the deformation of arterial wall. To see the cross section B, the velocity gradient is not significantly high near the arterial wall in the case with compliant wall, but due to the deformation of wall toward the direction shown by the arrow, the velocity gradient around the area C becomes high, and then WSS around the area C becomes high (see Fig. 3(a)). In the cross section C, there is no significant difference between the case with compliant wall and with rigid wall. Because around the cross section C, wall deformation is small and the physical relationship between the area with high axial velocity and the arterial wall does not change.

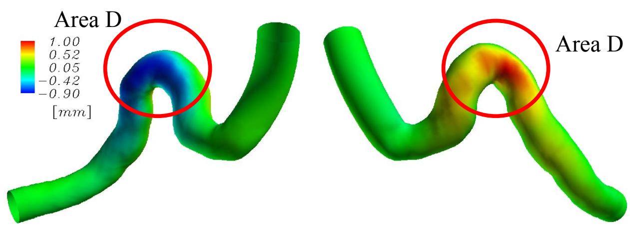
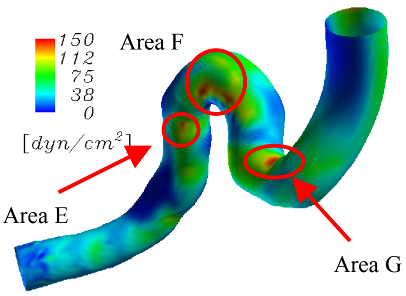
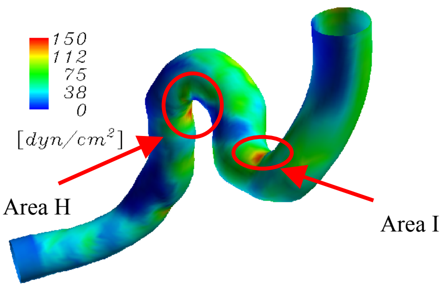


Figure 2. Wall deformation



(a) Elastic wall



(b) Rigid wall

Figure 3. Velocity distribution in some cross sections

CONCLUSIONS

To investigate the influence of wall deformation on the WSS distribution of arterial wall, the numerical simulation of interaction between blood flow and arterial wall has been performed. As results, it is shown that the physical relationship between the area of high axial velocity and arterial wall changes due to the deformation of the arterial wall.

REFERENCES

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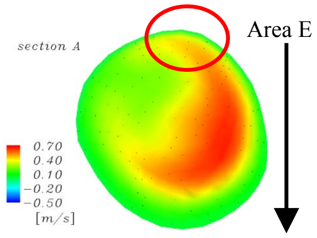
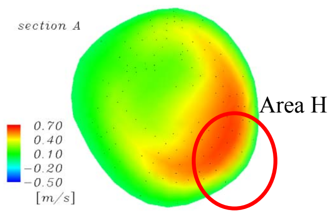
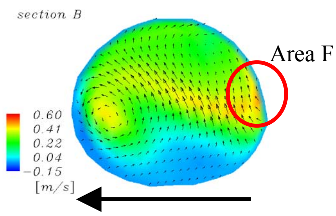
2. Malek, A. M., et al., 1999, JAMA, 282-21, 2035-2042
3. Tezduyar, T. E., et al., 1992, Comput. Meth. in Applied Mech. Eng., 94, 339-351



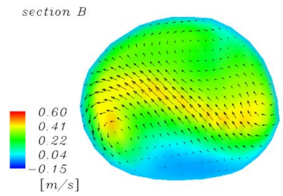
(a) Section A, compliant



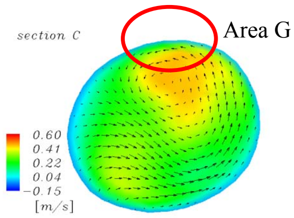
(b) Section A, rigid



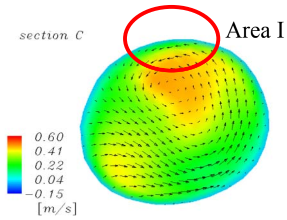
(c) Section B, compliant



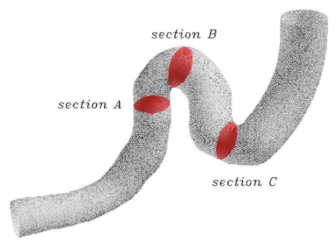
(d) Section B, rigid



(e) Section C, compliant



(f) Section C, rigid



(g) Cutting plane

Figure 4. Velocity distribution in some cross sections