Numerical Study of Blood-Flow Diversion Effects on Cerebral Aneurysm Using Stents with Various Porosities

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1. Introduction

The cerebral aneurysm is a balloon type tumor caused by blood pressure at weakened area on the wall of a blood vessel in the brain. Neglected aneurysm leads to an abnormal dilatation and massive bleeding [1]. Endovascular stenting is a non-invasive procedure which makes blood flow diverted to restrict blood from entering the aneurysm neck and reduces the risk of rupture of aneurysm. However, it is very difficult to quantitatively evaluate the effects of flow diversion. Therefore, a capability to analyze hemodynamics in the intracranial vasculature is highly required to reduce the amount of flow entering the aneurysm.

In this study, we modeled the aneurysm on the anterior cerebral artery (ACA) and two shapes of stent using computer aided design. Then, we analyzed the blood-flow diversion effect (that is, the reduction of flow rate from ACA into the cerebral aneurysm) of the stents with different sizes of porosities on the aneurysm by applying computational fluid dynamics (CFD). In this analysis, we used the Carreau model to describe the non-Newtonian behavior of the blood-flow. The transient initial conditions were used to reflect pulsation. Based on the computational results, we predicted flow diversion-rate by the stents when stent porosities varied from 63 % to 77 %.

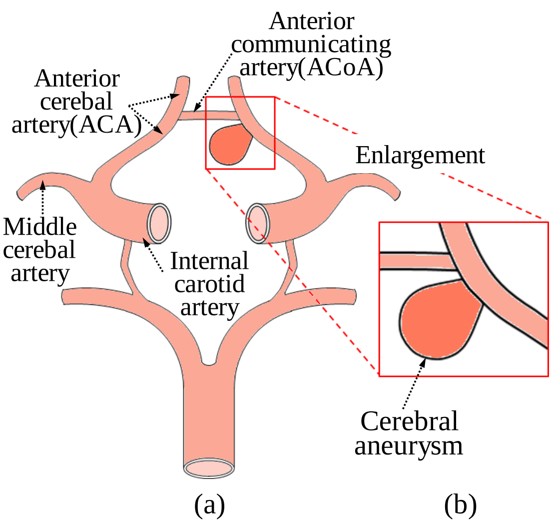

Fig.1 (a) Willis circle in the brain (b) Cerebral aneurysm located near ACoA

2. Modeling

2.1 Geometrical model of cerebral aneurysm

The cerebral aneurysms usually occur in the Willis circle which is circulatory anastomosis that supplies blood to the brain (Fig. 1(a)) Among them, aneurysms located near anterior communicating artery (ACoA) occur most frequently. In this research, we idealized the aneurysm configuration with a sac near the tip of a bifurcation as shown in Fig. 1 (b). Referring to actual human anatomy, the diameters of anterior cerebral artery (ACA) and ACoA were set at 2.6 mm and 1.5 mm, respectively.

2.2 Placement of the stent in blood vessel

The procedure for developing three dimensional geometry of the stent is as follows: In first, we constructed the stent from oppositely directed two ropes in two dimensional plane. By wrapping it in the circumferential direction, we reconstructed cylindrical stent. Then, we mounted the stent to fit into the blood vessel wall and finally placed it across the aneurysm neck in Fig. 1(b).

3. Blood-flow analysis

3.1 Analysis grid and boundary condition

We conducted a hemodynamic simulation of cerebral aneurysm using CFD analysis. All blood-flow regions are discretized with computational grids as shown in Fig. 2. Due to the

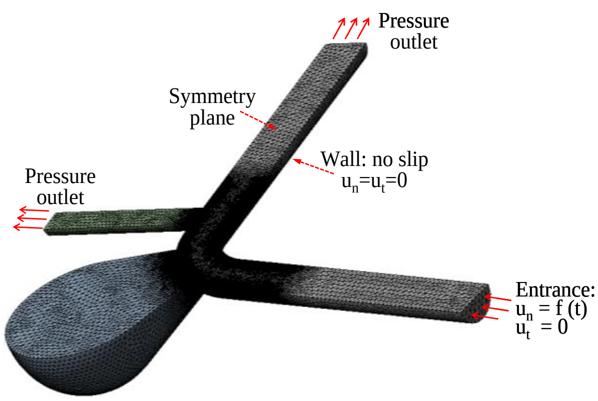

Fig.2 Grid and boundary condition of analysis domain

complexity of analysis domain (i.e. stented or non-stented), the grid size was ranged from 0.3 mm to 0.008 mm. The boundary conditions at the walls of the analysis domain were assumed to be rigid with no slip. 0 Pa was assigned to the pressure outlet boundary. A velocity profile pulsatile in time was prescribed at the inlet.

3.2 Constitutive equation of blood-flow

Since the blood is well-known to be non-Newtonian, we employed a non-linear viscosity model to describe the behavior of non-Newtonian fluid. Eq. (1) represent the viscosity model used in this study, which is known as Carreau model [2].

$$\eta = \eta_\infty + (\eta_0 - \eta_\infty)\left[1 + (\lambda \dot{\gamma})^2\right]^{\frac{n-1}{2}} \quad (1)$$

where, λ and n are characteristic time and exponent. η_0 and η_∞ represent viscosities at zero shear rate and infinite shear rate, respectively. These parameters are determined by a series of experiments.

4. Results and discussion

4.1 Flow diversion effects on cerebral aneurysm

The numerical analysis results of the velocity distribution of cross section around the neck of aneurysm are shown in Fig. 3. Fig. 3(a) shows the velocity distribution before stenting. Fig. 3(b) and (c) demonstrate the velocity distribution after stenting. The flow region of high velocity was dramatically reduced by the stent. This indicated that mesh structure of the stent blocked the blood flow and decreased its velocity. For the stent of low porosity (Fig. 3(c)), the flow velocity is drastically reduced as compared to the one of high porosity (Fig. 3(b)).

4.2 Wall shear stress at cerebral aneurysm

Fig. 4 shows wall shear stress (WSS) along the dome wall of the aneurysm. Rhombus symbols represent the WSS distribution before stenting. Circle and square symbols demonstrate WSS after stenting. In case of no-stent, local high shear stress was observed around the neck. It leads to long term damage of the endothelial cells and possibly rupture of the aneurysm. WSS was decreased by placing stent around the area of neck. With a stent of low porosity (square symbol), less blood can pass through the stent, resulting in a smaller maximum WSS. Reduction of WSS leads to an desirable environment in terms of rupture of the aneurysm.

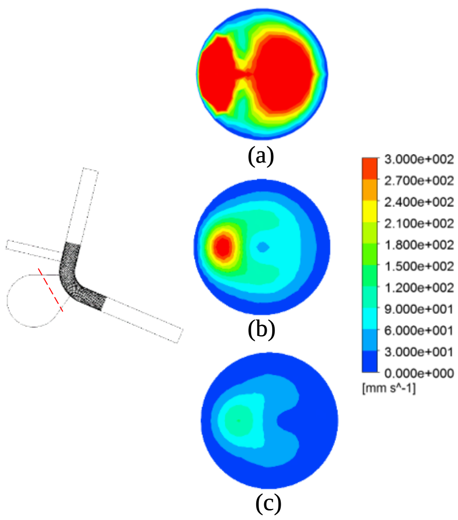

Fig.3 Velocity distribution of cross section around the neck of aneurysm: (a)before stenting (b) after stenting (porosity=77%) (b) after stenting (porosity=63%)

5. Concluding remarks

In this paper, we modeled the cerebral aneurysm on the anterior cerebral artery (ACA) and two shapes of stent with different porosities. A quantitative investigation of blood-flow diversion effects of the stent on the cerebral aneurysm was performed by applying computational fluid dynamics. We found that flow diverting effect (i.e. the reduction of blood-flow rate from ACA into the cerebral aneurysm) is remarkable by stenting. In addition, the stent with lower porosity was much more effective in terms of the flow diversion-rate. By placing stent in anterior cerebral artery, wall shear stress on the inner surface of the aneurysm was reduced to one-fifth of that without stent

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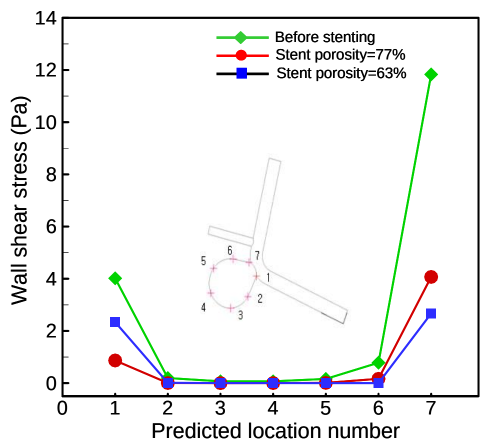

Fig.4 Wall shear stress (WSS) along the dome wall of the aneurysm