EFFECT OF STENT ON FLOW IN FUSIFORM ANEURYSMS

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INTRODUCTION

Cerebral aneurysms can be treated either by surgery or endovascular procedure [1-2]; however, certain aneurysms remain to be challenges for treatment. For example, fusiform aneurysms are unsuitable for existing treatment procedures. Thus, stenting becomes an experimental alternative for these hard-to-treat aneurysms, and many successful clinical cases have been reported [3-4]. Recent experimental and theoretical studies [5-6] have focused primarily on stenting of saccular aneurysms, which can be treated by other procedures without stent placement and has high rate of obliteration [7], while few studies focused on stenting of fusiform aneurysms. Thus, the working principle behind treatment of fusiform aneurysms with stents is still unclear. In this study, we aim to investigate the flow in stented fusiform aneurysms and evaluate its clinical implication.

METHOD

A fusiform aneurysm with a width to length ratio of 0.5 is stented by generic strut patterns that are varied by changing the periodicity in both the longitudinal and circumferential directions. FLUENT 6.0 (Lebanon, NH) is used to solve the Navier-Stokes equations, and both the steady and pulsatile flows are analyzed. Blood is assumed to be incompressible and Newtonian, and the flow is modeled as laminar flow. The diameter of the aneurysm is 10 mm, which is twice the diameter of the artery. The mean velocity in the artery is 10 cm/s, and the resulting Reynolds number is 150. Since the flow is slow in the aneurysm, the solution is considered to be convergent when the residual has been reduced five orders of magnitude. Because of symmetry, only a quarter of artery is modeled in the simulation.

RESULTS

Streamlines for two different configurations of stent are presented in Figure 1. The streamlines in the middle of grid cell are different from straight lines, demonstrating weak vortical structure in the longitudinal direction. The velocity component in the direction of strut is very small; this is similar to the cases of stented carotid artery, so the viscous forces are minimized.

There is a 90% increase of intra-aneurysmal inflow and 50% increase of vorticity, as shown in Figure 2. However, the wall shear on the aneurysm is reduced by 40%. Therefore, the increase of aneurysmal inflow does not lead to an increase of wall shear.

Intra-aneurysmal inflow, voriticity, and flow shear on the stent strut and aneurysm during a pulsatile cycle are shown in Figure 3. The temporal variation of intra-aneurysm inflow and vorticity behave similar to those before the stent is placed except that the aneurysm wall shear is 50% higher before the placement of stent. The flow shear on the surface of strut is the only flow quantity that follows a similar sinusoidal pattern specified at the entrance of the artery. Intra-aneurysmal inflow lags the arterial waveform by $\pi/3$, and so does the wall shear on the aneurysm. The average vorticity within the aneurysm follows the arterial waveform closely except when the flow rate is near the minimum, demonstrating a strong inertia effect.

DISCUSSION

Unlike the flow in stented saccular aneurysms, stenting fusiform aneurysm promotes intra-aneurysmal inflow; however, the wall shear is reduced after stenting. The increase of intra-aneurysmal inflow and vorticity and decrease of wall shear indicate that majority of flow activity stays close to the struts and is away from the aneurysm wall. In fact, the increase of intra-aneurysmal flow can be attributed to a wide neck that exposes the aneurysm to the flow in the artery.

Two stents perform similarly for pulsatile flow except that the wall shear on the aneurysm for case B is twice the magnitude of that for case A during deceleration. Since only the dynamic pressure and aneurysm wall shear have been reduced, stenting aneurysm may not be useful if thrombus formation is independent of these two hemodynamic variables. In saccular aneurysms, all the variables that are used to describe flow activity decrease after stenting, so it may be difficult to distinguish their individual effect.

Presence of stent strut disrupts and disturbs the flow in the aneurysm. The level of flow activity is higher after the stenting, but the wall shear is reduced because the struts generate small scale vortices. The flow in stented fusiform aneurysms is very different from that in stented saccular aneurysms; thus, application of stent to cerebral aneurysms results in completely different hemodynamic environment and may lead to different clinical consequences. To improve the effectiveness of an endovascular procedure that uses stents relies on further characterization and understanding of the hemodynamic environment in the aneurysms after the treatment.

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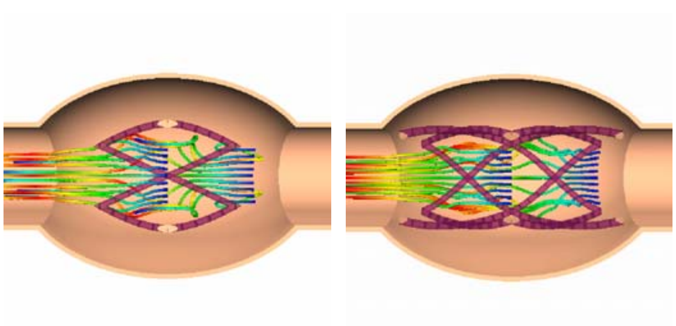

Figure 1. Streamlines in fusiform aneurysm treated with stent. Only half of the aneurysm and stent are shown. The stents are shown in dark color, while the streamlines change color as fluid particles move.

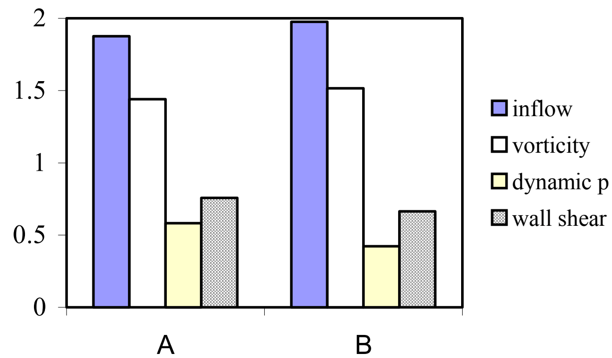

Figure 2. Comparison of flow activity in fusiform aneurysms after the treatment. Refer to Figure 1 for the type of stents used in the study. The flow variables are normalized by the values before the stenting. It shows that the intra-aneurysmal inflow is nearly doubled after the stenting, while the dynamic pressure is reduced by 50%. The intra-aneurysm inflow is evaluated by the amount of fluid crossing the neck of aneurysm. The voritcity, an average of total vorticity within the aneurysm, is a measure of the strength of flow activity in the aneurysm. Average dynamic pressure at the neck of the aneurysm is used because the change of static pressure is not significant.

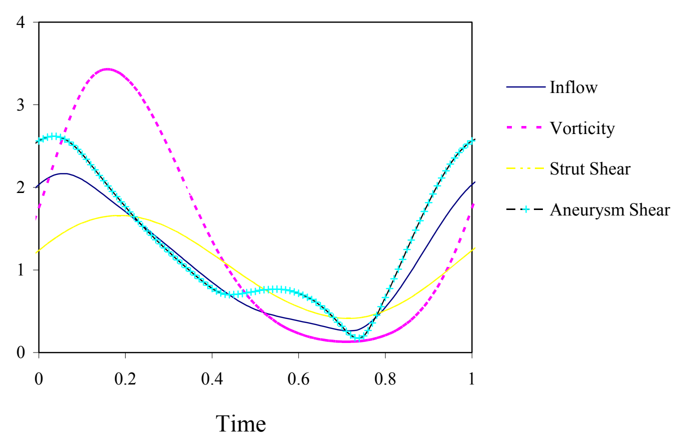

Figure 3. Flow activity in the aneurysm during one cardiac cycle for case A. The variables are normalized by the values for the steady flow after the stenting.