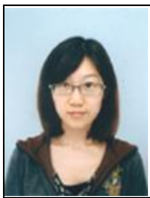
Comparison of intra-aneurysmal velocity magnitude in a patient-specific model among PIV, CFD and MRI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Abstract :

1. Introduction

Cerebral aneurysm rupture has been one of those most dangerous disease threatening people's health, and with those current medical facilities, aneurysms are possible to be detected before it rupture. Since the process of the treatment to aneurysms also has a high risk that may cause some severe damage to the patient, medical doctors are faced with a hard decision of whether to treat those aneurysms or not[1].

Hemodynamics, such as flow pattern, velocity, pressure and wall shear stress, is thought to be a very important factor related to the rupture of cerebral aneurysms. Thus, it is widely believed that the understanding of the hemodynamics of the aneurysm may help medical doctor to assess the risk of the aneurysm and then make the decision of whether to treat or not.

In order to discuss the condition of the aneurysm by evaluating the intra-aneurysmal flow patterns, velocity vector fields inside the patient-specific aneurysm has been selected to study with different methods in many researches, like particle image velocimetry (PIV), cine phase-contrast (PC) MR imaging (MRI) and computational fluid dynamics (CFD)[2].

Comparisons of the hemodynamics in patient-specific model between PIV and CFD , and between MRI and CFD have been studied, respectively[1,2,3], showing agreement and disagreement at different points in the results. Each method has its own advantages and limitations. However, comparison of same geometry among PIV, CFD and MRI has never been done, which is important for achieving better results and providing accurate hemodynamics to medical doctors, and also necessary for us to be aware of the good behaviors and drawbacks in each method. Therefore, the purpose of this research is to learn the accuracy and difference in the results of measurement or calculation by different methods of PIV, MRI and CFD. Quantitative comparison of intra-aneurysmal velocity magnitude on the certain target plane in the results of these three methods will be taken out. This work is relatively related to BioCath [B].

2. Materials and Methods

- Silicone Models for PIV and MRI

In this research, realistic cerebral aneurysm has been detected on a 3T MR imaging scanner (MAGNETOM Verio 3T, Siemens) by using a 12 channel head matrix coil. 3D TOF MR angiography was performed with a scan resolution of 0.25×0.25×0.25 mm. Imaging parameters were set as following: TR/TE, 25.00/4.67 msec; flip angle, 18°; acquisition time, 5 minutes 39 seconds. The corresponding STL file has been reconstructed, based on which the silicone phantom has been manufactured (R-tech Co. Ltd.), as shown in Fig.1. Plane A located around the aneurysm neck has been selected as the target plane to compare the hemodynamic result among PIV, MRI and CFD.

- Geometry for CFD Simulation

Considering of the geometrical changes that might have been caused during the fabrication with the 3D printer, the silicone phantom were scanned by a Micro-CT scanner (ScanXmate-D180RSS270, Comscantec Co. Ltd.). The lumen boundary was extracted and reconstructed from the resulting high-resolution DICOM data to a STL file using a commercial medical image processing software (OsiriX 64bit). After this processing, the silicone phantom geometry and the geometry used for CFD simulation are considered to be equivalent.

- Working Fluid for PIV and MRI

Working fluid has been created and used in both MRI measurement and PIV experiment, which has similar property to human blood. For the two manners, slightly different compositions of materials have been used in the working fluid to meet the requirements of each method, which may lead to some discrepancies in the properties of the working fluid.

- MRI Measurement

Silicone model was connected into a circulation system, which had working fluid running in the system under the inlet velocity collected from the patient data. 3D cine PC MR imaging was performed with resolution of 0.5 mm. Imaging parameters were set as following: TR/TE, 62.48/3.88 msec; flip angle, 15°; acquisition time, 16 minutes 16 seconds.

- PIV Experiment

Same circulation system to the MRI measurement has been established in the PIV experiment. A straight tube with 1-meter-length has been added to the inlet of the silicone phantom, in order to provide enough distance for the flow to be fully developed before entering the aneurysm. High speed camera (FASTCAM SA3, Photron limited Co. Ltd.) with resolution of 17 um was set to acquire images of the particle movement on the target plane, which has the light source provided by an Nd: YAG laser (DPSS laser system-532NM X 300MW, Edmund Optics Co. Ltd) on it. The laser sheet was 1mm thick.

- CFD Simulation

Mesh volume of 1.9 million has been generated in the STL file with tetrahedral mesh and three boundary layers (ANSYS ICEM CFD, ANSYS Inc.). Steady flow condition was applied to the simulation, and the Reynolds number at inlet was controlled at a similar level at around 500. The flow simulation was performed by using a commercial solver (Ansys Fluent Inc., USA) based on finite volume method.

3. Results and Discussion

- Results of flow patterns

As shown in Fig.2, flow patterns on Plane A in different methods have been displayed, the flow rotates in the anti-clockwise direction, generating a vortex in the center of the plane in a similar way. However, it is obvious to find out that flow pattern at the top area of Plane A obtained from MRI is different, in which no separate point can be seen.

- Results of average velocity

The average velocity on the target plane in each method has been calculated. While results of flow patterns in different methods tend to be in accordance with each others, the velocity magnitudes apparently show disagreement to some extent, in which the velocity magnitude calculated in CFD is higher than those in PIV and MRI.

4. Acknowledgement

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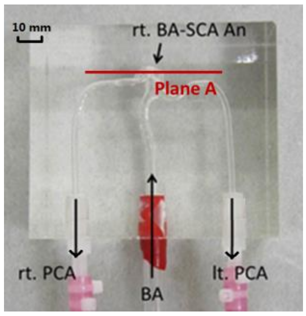

Fig.1 Silicone model of the patient-specific aneurysm and position of the target plane

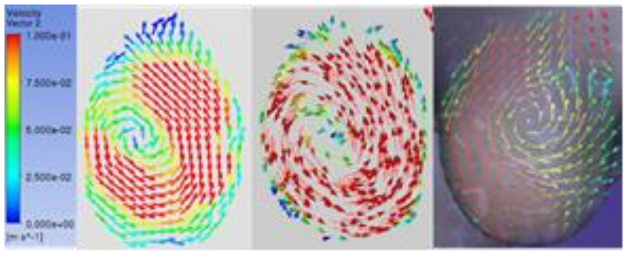

Fig.2 Flow patterns on Plane A : PIV, CFD, MRI (from left to right)

References:

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