Visualization of Hemodynamics in a Silicon Aneurysm Model using Time-Resolved Three-Dimensional Phase-Contrast MRI

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PURPOSE

Hemodynamics affects the development and growth of intracranial aneurysms. If we could estimate the rupture potential of aneurysms based on hemodynamics then only patients with aneurysms that show high rupture potential would undergo treatment. This would be beneficial for all patients and be cost effective. The purpose of our study was to visualize hemodynamics in a silicon vascular model with a middle cerebral aneurysm using Time-Resolved Three-Dimensional Phase-Contrast MRI (4D-Flow) (1).

MATERIALS & METHODS

We obtained a rotational angiographic data set of the right internal carotid artery for a 67-year-old female with an unruptured right middle cerebral aneurysm with a fundus diameter of 8mm. Multiple two-dimensional slices of the vascular structure were created with a workstation. These DICOM data sets were processed to reconstruct the lumen of the vessels in three dimensions and then transferred to a three-dimensional printer using powders and adhesive to produce a master cast of the vascular lumen. Based on this master cast, realistic silicon model, three times actual size, with a right internal carotid artery containing the lumen of the original vessels was then constructed (Fig. 1). We ran an aqueous solution of glycerol (T1 value, 1005msec; T2 value, 86msec) as a flowing fluid through the silicon vessel model by a pulsatile pump (one cardiac cycle = 2sec, maximum systolic velocity = 84cm/s, Reynolds number = 810.8, Womersley number = 3.26). Three-dimensional TOF MR angiography (Fig.2) and 4D-Flow were performed with 1.5T MR scanner. The 4D-Flow technique is based on a radiofrequency-spoiled gradient-echo sequence and it encodes flow velocity in three orthogonal directions. It can provide us with four-dimensional flow information including space and time. The 4D-Flow technique was carried out with the following parameters; TR/TE/NEX=5.8/2.1/1, FA=15, FOV=140x140x108mm, Matrix=160x160x36, VENC=20cm/s, 20 phases during one cardiac cycle, imaging time=30min, axial plane, ECG trigger. Three-dimensional stream lines and three-dimensional particle traces within the aneurysm and adjacent parent arteries, and two-dimensional velocity vector fields on arbitrary planes were calculated using visualization software (EnSight).

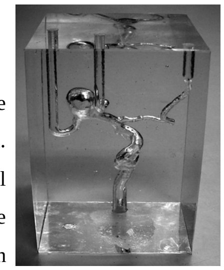

Fig.1 A silicon model with an unruptured middle cerebral artery.

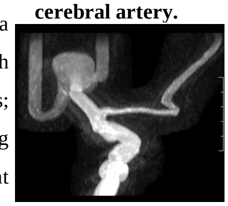

Fig.2 3D TOF MR angiography.

RESULTS

Time-resolved images of three-dimensional stream lines (Fig. 3) and particle traces clearly demonstrated that the aneurysm had three-dimensional complex vortex flows within it during systolic phase and that flow streams ran out into the two adjacent M2 branches of the middle cerebral artery. Two-dimensional velocity vector fields (Fig4A, B) on arbitrary planes clearly showed time-resolved flow velocities within the aneurysm and the parent arteries.

CONCLUSIONS

In our model the 4D-Flow technique provided us with time-resolved three dimensional hemodynamic information about the intracranial aneurysm and the adjacent parent artery. This is a promising technique for visualizing and analyzing intraaneurysmal hemodynamics.

REFERENCE

1. Markl M, et al. Time-Resolved Three-Dimensional Phase-Contrast MRI. J Magn Reson Imaging 2003;17:499–506.

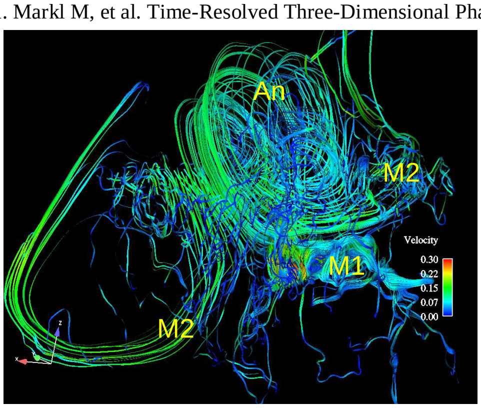

Fig.3 Three-dimensional stream lines of the aneurysm model. An, Aneurysm; M1, M1 segment of the middle cerebral artery; M2, M2 segment of the middle cerebral artery.

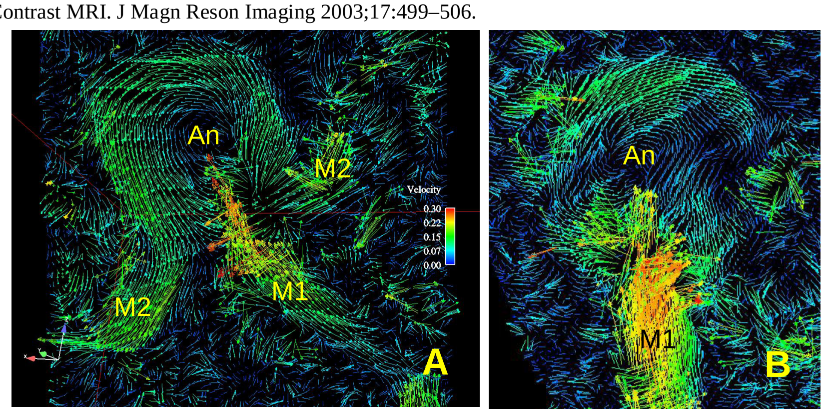

Fig.4 Two-dimensional velocity vector field of the aneurysm model. A and B show different planes. An, Aneurysm; M1, M1 segment of the middle cerebral artery; M2, M2 segment of the middle cerebral artery.