

Hemodynamic forces in the progression of intracranial aneurysm change as assessed using MR-based methods

David Saloner¹, Evan Kao², Gabriel Acevedo-Bolton², Andrew Lee², Petter Dyverfeldt², and Vitaliy Rayz²

¹Radiology and Biomedical Imaging, VA/UCSF, San Francisco, CA, United States, ²Radiology and Biomedical Imaging, UCSF, San Francisco, CA, United States

INTRODUCTION: Hemodynamic forces have long been thought to be important in determining what features drive changes in aneurysm morphology over time. However, which specific properties of hemodynamic factors that lead some aneurysms to grow rapidly while others remain stable, remain controversial. We have reported elsewhere on a study in progress where we are following patients with untreated aneurysms [1] over time. 15% of those subjects have shown increases in aneurysm volume that is significantly greater than measurement error. This presentation reports on MR-based analyses of velocity fields and hemodynamic forces in this patient population. The aim of this study was to determine whether it was possible to identify hemodynamic features that were different in aneurysms that changed, in comparison to those that remained stable over time.

METHODS: We have studied 78 patients with 88 aneurysms of the intracranial circulation with serial imaging using an IRB-approved protocol. Of these, 14 aneurysms had intraluminal thrombus [2]. Of the aneurysms that remained thrombus-free, studies were performed at intervals from 6 months to 1 year for a total of 226 interval measurements. At each imaging session MRA and MRI studies were conducted at 1.5T to assess luminal volume and whether there was any thrombus present in these aneurysms. A contrast enhanced 3D MRA study was acquired with a parallel acceleration factor of 2 resulting in high-resolution (0.6 x 0.63 x 1.2 mm) images of the cerebral vessels. Phase contrast MR velocimetry was performed for through-plane flow in slices transverse to the feeding arteries.

Serial MR studies were co-registered using internal fiducial markers. Consistent thresholding was imposed by requiring that a reference segment of undiseased vessel maintained the same luminal volume over time. The luminal volume of the aneurysmal segment was then assessed on the CE-MRA studies for regional and global changes. Computational Fluid Dynamics (CFD) calculations were performed with boundary conditions based on the aneurysm geometry and the inlet flow conditions in subjects where the aneurysm was found to grow, and in matched subjects whose aneurysm remained stable over time. Wall shear stress was computed over the surface of each aneurysm

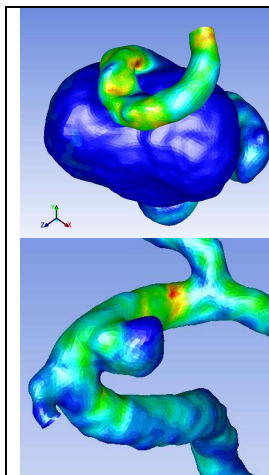


Fig. 1: Computed wall shear stress on two saccular aneurysms. Above: WSS on an aneurysm that was found to grow over time. Below: WSS on an aneurysm that remained stable over time.

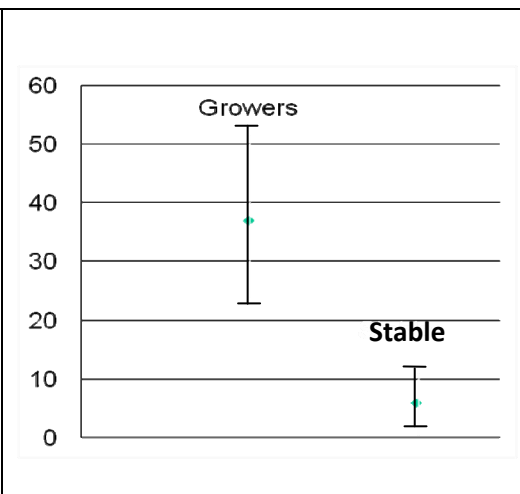


Fig 2: Fraction (in %) of surface area of aneurysm that is exposed to wall shear stress lower than 0.3 N/m² for two groups: one that showed increase in volume over time and the other group that remained stable over time.

In order to validate the CFD predictions, exact replica flow models were constructed of four representative aneurysms and the full four-dimensional velocity field was measured for physiological flow using 4D MR velocimetry.

RESULTS: Excellent agreement was found between experimentally measured velocity fields and CFD predicted velocity fields, even for highly complex flow fields. For the CFD analysis, large regions of slow and recirculating flow were predicted by CFD in regions that were found to layer thrombus. In the 74 aneurysms that remained thrombus-free, 11 were found to grow. Histograms of the frequency of wall shear stress as a fraction of the total surface area of the aneurysm indicated that aneurysms that grew had a substantially larger fraction of the surface area of the aneurysm exposed to low wall shear stress than aneurysms that remained stable over time. In aneurysms that grew, the mean surface area exposed to wall shear stress lower than 0.3 N/m² was found to be 38% compared to 6% in aneurysms that remained stable (Fig. 2). Furthermore, regions of observed growth were found to be co-located with regions of low wall shear stress.

DISCUSSION: MR-based CFD studies provide the means to evaluate the link between hemodynamic forces and the evolution of vascular disease. Experimental MR velocimetry indicates that CFD predictions are accurate. An approach using MR methods to assess growth and to provide boundary conditions for CFD analysis, indicates that low wall shear stress is related to an increased rate of aneurysm growth. Identifying those factors that indicate which aneurysms are at risk for rapid disease progression would be of great importance in helping clinicians

REFERENCES: [1] Saloner et al ISMRM 2012; [2] Rayz Ann Biomed Eng. 2010; 38:3058-69