In vivo MR determination of flow fields in patients with intracranial aneurysms using 7D PC-MRI

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Introduction

Recent results indicate that hemodynamic forces play an important role in the progression of aneurysmal disease, both in the growth of the lumenal surface, and in the likelihood of thrombus deposition. However, flow fields in aneurysmal geometries are frequently quite complex and images of either a single velocity component or of a single plane of data fail to elucidate the relevant flow dynamics. We have used MR velocimetry (MRV) methods that determine the full velocity vector at all points in 3D space and through the cardiac cycle to investigate flow patterns in patients with intracranial aneurysms. The measured flow fields were also compared with in vitro reproductions of these geometries, and with the predictions of simulations using computational fluid dynamics (CFD) methods.

Methods

Six patients with intracranial aneurysms were enrolled using IRB consent. Patients were imaged with CE-MRA and 7D-PC-MRI. A time-resolved 3D PC-MRI sequence with imaging parameters of FOV = 240mm x 190mm x 12mm, TR=8.1ms, TE=3.7ms, flip angle =8°, VENC=40-80 cm/s, matrix 240x190x12, isotropic 1mm resolution, SENSE factor =1.6 and an imaging time of 10 min, was implemented with velocity encoding along each of the three encoding axes, and cine imaging was performed to determine the velocity vectors through the cardiac cycle. The acquired data was postprocessed to display the velocity vectors in multiple planes and projections. Similar MRV acquisitions were performed on exact replica flow models using patient-specific flow conditions to confirm the in vivo findings. Also, CFD simulations were performed to serve as a reference standard. CE-MRA and PC-MRI were used to determine lumenal geometry and flow waveforms in the inlet and outlet vessels, respectively. Results from the different approaches were compared.

Results

The in vivo 7D PC-MRI studies provided clear depiction of important hemodynamic features such as regions of low wall shear stress, and vorticity (Fig.1). The ability, provided by the three dimensional spatial coverage, to reformat data in multiple views was helpful in elucidating the flow dynamics. Similarly, it was found to be essential to determine all three components of the velocity to adequately visualize the complex flow structures. Direct comparison of the in vivo results with both in vitro flow models and with CFD simulations demonstrated excellent qualitative agreement as to the location and extent of structures such as flow jets and impingement zones (arrows in fig. 2)

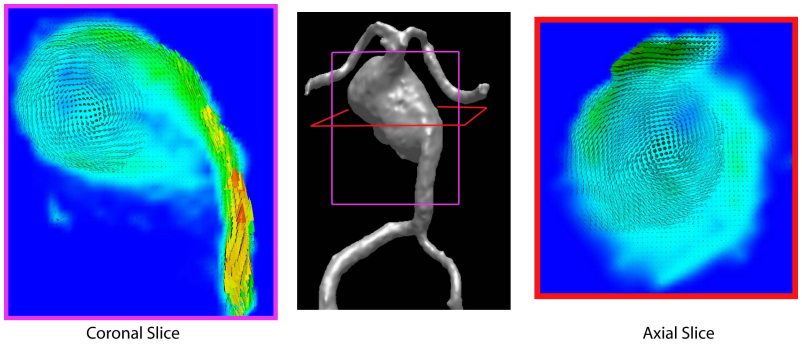

Figure 1: Velocity field measured in vivo in a patient with a giant fusiform aneurysm (CE-MRA center) formatted in coronal (left) and axial planes (right).

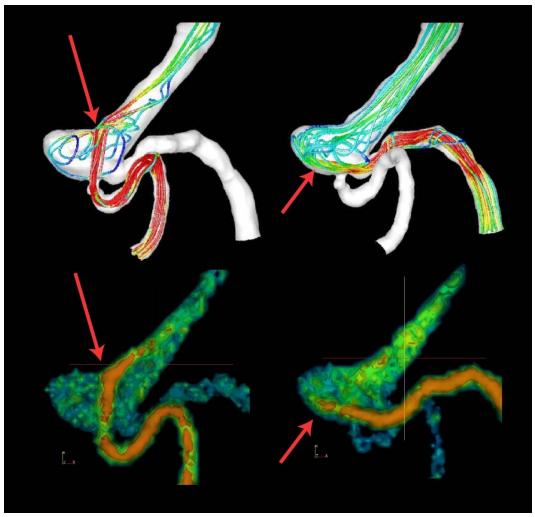

Figure 2: A comparison of the CFD results (top) and in vitro MRV (bottom) for two different flow conditions showing excellent correlation of the impingement zones (arrows).

ConclusionThis study demonstrates that 7D MRV is a powerful modality for the evaluation of complex flow structures in intracranial aneurysms. Important features of the flow were demonstrated, including flow jets, vortices, and impingement zones, and these measurements were validated against in vitro studies and numerical simulations. The ability to determine velocity fields in vivo offers the promise of being able to predict important features of the progression of aneurymal disease over time, such as lumenal expansion or thrombus deposition.