Reproducibility of flow measurements in serial studies of patients with untreated aneurysms

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INTRODUCTION: MR velocimetry provides a unique capability to provide non-invasive measurements of volume flow, particularly in evaluation of intracranial vessels that are not accessible to ultrasound. This capability is of particular value in establishing boundary conditions for Computational Fluid Dynamics (CFD) calculations that can predict the distribution of hemodynamic factors, such as wall shear stress (WSS), that are postulated to impact the evolution of vascular disease. There have been extensive studies in simplified models of flow such as straight tubes or rotating disks, to evaluate the accuracy of phase-contrast MRV methods. However, performance of these MRV methods in vivo and in complex geometries remains questionable. We report on in vivo and in vitro studies in geometries that present in intracranial aneurysms. In particular, we have evaluated the reproducibility of 2D through plane flow measurements in subjects with intracranial aneurysms where studies were performed annually over many years, and in exact replica models of these aneurysms, in a subset of these subjects using 2D and 4D MRV methods.

METHODS: We have studied 78 patients with 88 aneurysms of the intracranial circulation with serial imaging using an IRB-approved protocol (1). Subjects were evaluated at intervals from 6 months to 1 year for a total of 226 interval measurements. At each imaging session MRA studies were conducted at 1.5T to assess lumenal volume. In addition, through-plane MRV was measured in planes transverse to the feeding arteries to the aneurysm to establish boundary conditions for subsequent CFD studies. In selected subjects with aneurysms that were larger than 10 mms in diameter, 4D time-resolved MR velocity fields were measured. Exact replica models were constructed of 4 of the aneurysms and 4D velocity fields were measured and calculated for those models using physiological pulsatile flow (Fig. 1). Computational Fluid Dynamics (CFD) calculations were performed with boundary conditions based on aneurysm geometry and inlet flow conditions. In the 4 exact replica models, the reproducibility of measurements was assessed for varying VENC settings, and voxel sizes. This was achieved by evaluating the variability of velocity measurements over 10 repeated measurements with the same flow conditions.

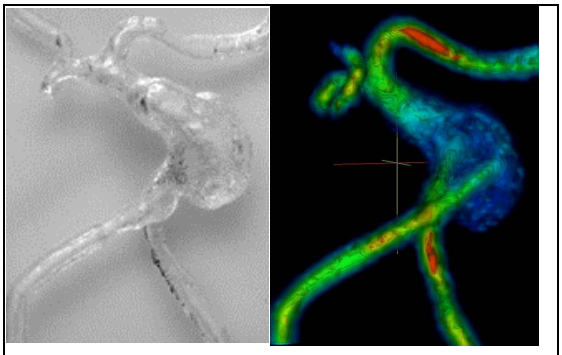

Fig. 1: Left: Exact replica flow model of fusiform basilar artery aneurysm. Right: MIP of measured 4D velocity field on the coronal plane for the flow model on the left.

RESULTS: The flow models permit the determination of flow reproducibility as very lengthy studies can be repeatedly performed in complex geometries with unchanged flow conditions – something that is not practical in vivo. Excellent agreement was found between experimentally measured 4D velocity fields and CFD predicted velocity fields, even for highly complex flow fields (2). Studies with smaller voxels and lower VENC settings were found to have results with reduced measurement variation. For the in vivo studies, sensitivity to definition of the region of interest remains an important limitation (Fig. 2). Fluctuating noise in voxels immediately adjacent to the ROI were found to be substantial in some phases of the cardiac cycle. In general, measurement of peak flow was found to be reproducible to within 10% over measurements in the same subjects made in intervals as much as 7 years apart (Fig. 3).

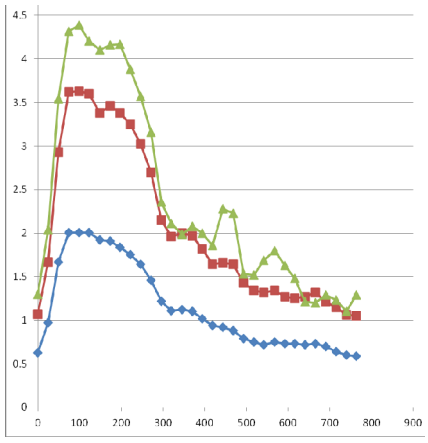

Fig. 2: Through plane flow measurements with 3 different ROIs show volume flow through the cardiac cycle. Small (blue), matched (red) and large (green) show underestimation of flow with ROIs that are too small and large error fluctuations with ROIs that are too large.

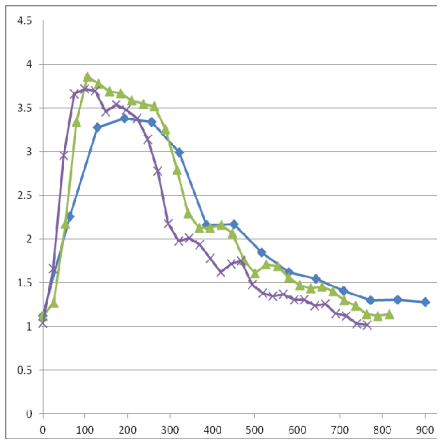

Fig 3: Through plane flow from representative studies made at three time points in the same patient with an internal carotid artery aneurysm over a period of 7 years between first study (blue) and last study (purple).

DISCUSSION: MR imaging is a powerful method for the assessment of volume flow, something that cannot be non-invasively determined in vivo with other modalities. Experimental flow models can be constructed that permit the determination of the factors that could reduce error of measurement using MR velocimetry. Improved resolution and lower settings of VENC can reduce measurement error. Our studies in a large cohort of subjects with intracranial aneurysms indicate that current methodologies permit the acquisition of flow values that remain consistent over many years to within 10%.

REFERENCES: [1] Saloner et al ISMRM 2012; [2] Boussel et al Magn Reson Med. 2009;61:409-17