Computational Fluid Dynamics (CFD)-based Flow Analysis in Aneurysms: A Comparison Study with 4D Phase-Contrast MR in an In Vivo Canine Aneurysm

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INTRODUCTION: The origin, growth and rupture of intracranial aneurysms are associated with chronic exposure to hemodynamic stresses. Accurate assessment of hemodynamics in and around aneurysms could advance the understanding of those hemodynamic factors signaling the vascular remodeling that is responsible for the progression and rupture of aneurysms; it might also be useful in planning and evaluating therapeutic interventions. Both patient specific CFD modeling [1] and MR velocimetry measurements [2] have been increasingly used to study blood flow in aneurysms and to derive clinically-relevant hemodynamic parameters such as wall shear stresses and relative pressures. Although validations of both techniques using simple vessel geometries or *in vitro* vessel models have shown favorable agreements, few studies have been conducted to assess the differences in flow patterns between that predicted by the CFD and those measured by *in vivo* PC-MR acquisitions. In this study, we compared the results of CFD simulations and novel 4D-PC-MR velocity measurements in an experimental canine aneurysm [3].

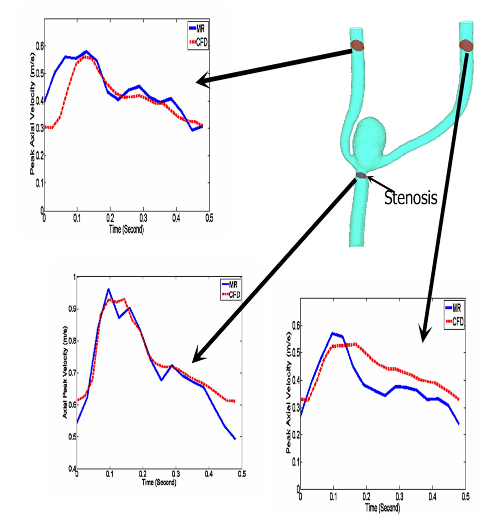

Figure 1. Comparison of maximum axial velocity between the CFD simulation and 4D MR flow imaging at three given cross-sections of a bifurcation aneurysm.

MATERIALS AND METHODS: Following local Animal Care and Use Committee approval, four experimental canine bifurcation aneurysms [3] were studied. MR imaging was performed with a 1.5-T clinical scanner (Signa HD, GE Healthcare, Waukesha, WI, USA). 4D three-directional velocity measurements were acquired using PC-VIPR [2] which employs a 3D radial trajectory for accelerated PC imaging. Parameters used for the PC-VIPR data acquisition include: TE/TR (3.6/14.0), bandwidth (±31.25 kHz), FOV (18x18x18-cm^3), Venc (±1.5m/s), isotropic resolution of 0.8mm,, temporal resolution of 56ms, scan time: 8:00 min.

A commercially-available CFD solver (FLUENT 6.2, ANSYS-FLUENT Inc., NH) was used for the CFD simulations. the aneurysm geometry was first reconstructed from 3D-Digital Subtraction Angiographic data (3D-DSA Siemens Artis, Siemens AX Healthcare, Forchheim, Germany) using a commercially-available image segmentation package (Simpleware Inc., UK) and was subsequently meshed. Boundary conditions for inlet and outlet blood waveforms were established using values from the PC-MR and Ultrasound Doppler measurements (pulsating frequency 6.3 MHz, VFX 13-5, Siemens Medical Solution (USA) Inc., CA).

The data sets from the 4D-PC-MR acquisition and the CFD simulation were manually registered. Then, EnSight (CEI Inc., NC) in conjunction with Matlab (Mathworks Inc., MA) routines made in-house was used for interactive visualization of 3D velocity vector fields and quantitative comparisons.

RESULTS: For comparison, cross sectional planes through the aneurysm and parent arteries (upstream and downstream) were chosen for each animal. Cross-sectional velocity profiles were compared at fifteen time points during the cardiac cycle. Qualitative comparison of axial velocity profiles revealed favorable agreement (Pearson correlation coefficient > 0.9) between the simulations and MR measurements in the peak cross-sectional velocity as shown in Figure 1 for all cross-sections investigated. Reasonable correspondence was also observed in the aneurysm domes with both approaches showing similar velocity profiles (*e.g.* velocity amplitudes [show in Figure 2], contours and streamlines).

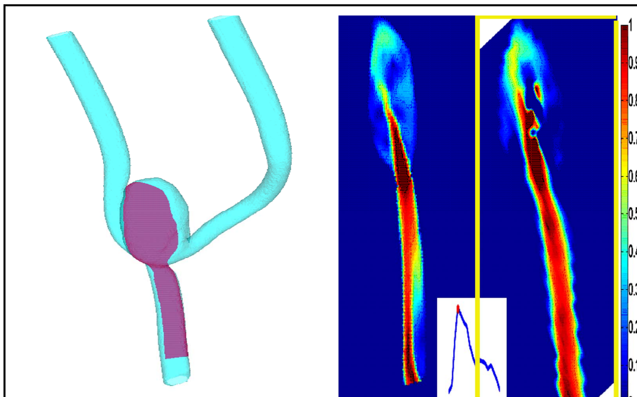

Figure 2. Comparison of velocity amplitude profiles between the CFD simulation (middle) and 4D MR flow imaging (right) at a cross-sectional plane (left) in a bifurcation aneurysm parallel to the blood flow direction at the peak systole.

CONCLUSIONS: Our results show good agreement between the CFD simulations and the 4D PC-MR measurements. Future work is ongoing to extend our studies to human intracranial aneurysms.

REFERENCES:

[1]. Steinman D. A. Ann. Biomed. Eng., 2002; **30**: 483-97; [2] Gu T, et al. AJNR 2005; 26: 743-9; [3] Strother CM, *et al.* AJNR, 1992; 13: 1089-95.