High Resolution Hemodynamics of Small Intracranial Aneurysms with Phase Contrast Stack of Stars

S. Kecskemeti[1], K. Johnson[1], Y. Wu[1], P. Turski[2], and O. Wieben[1]

[1]Medical Physics, University of Wisconsin - Madison, Madison, Wisconsin, United States, [2]Radiology, University of Wisconsin - Madison, Madison, Wisconsin, United States

Introduction: Endothelial wall stresses are thought to play an important role in regulating aneurysm growth and formation [1,2]. Measurement of relevant parameters (e.g. wall shear stress) from phase contrast(PC) MR velocity fields requires very high spatial resolutions which is difficult to achieve in clinically feasible scan times. We investigated the utilization of a phase contrast (PC) stack of stars (SOS) acquisition [3] for targeted cine 4D PC MR with ultra-high spatial resolution to provide anatomical and hemodynamical visualization of small intracranial aneurysms. In this study, we imaged 12 aneurysms of sizes 2-10mm, with 7 of them 4mm or less.

Methods: Eleven patients with 12 known intracranial aneurysms were imaged on a clinical 3T scanner (MR 750, GE Healthcare, Waukesha, WI) using an 8 channel head coil after obtaining IRB approval and written informed consent from all subjects.. Following a contrast enhanced MRA, patients were scanned with PC SOS and 5-pt velocity encoding [4] using: FOV 220x220x30-40mm, acquired resolution 0.43x0.43x0.7-1.0mm, TE/TR = 3.7/8.0ms, tip angle = 20 deg, BW = 83.3 kHz, scantime = 9 minutes. PC derived angiograms were analyzed for aneurysm conspicuity and were used to construct surface renderings (Fig1). Dynamic velocity fields were reconstructed with retrospective ECG gating and radial view sharing [5] with 40ms temporal resolution and used for hemodynamic visualization with a dedicated software package (EnSight, CEI Inc., Apex, NC).

Results: All 12 aneurysms were successfully identified in the 11 PC SOS exams (see surface rendered images in Fig. 1). A representative PC MRA used for anatomical diagnosis, surface renderings, and masks for hemodynamic analysis in EnSight is shown in Fig. 2. The high spatial resolution and strong background suppression typical of PC SOS aid in visualization of this aneurysm, measured to be 3.8mm at its neck. The high spatial resolution aids in proper visualization of streamlines here showing a helical circulation pattern within the aneurysm, despite its small size. A small carotid terminus aneurysm, measured as 2.3mm at its neck is used to demonstrate the benefits and necessity for high spatial resolution obtained. Figure 3a shows the blood entering the aneurysm from the internal carotid artery with high speed and then slowing as it circulates and eventually exits to the anterior cerebral and communicating arteries. Flow maps calculated at a plane placed at the aneurysm neck (Fig 3b), demonstrate this behavior in Fig 3c. However, when the same velocity maps were visualized after MR image reconstruction from the identical k-space data but at lower spatial resolutions of 1.0x1.0x1.0mm and 1.5x1.5x1.5mm, typical of Cartesian 4D PC MR acquisitions, this behavior was not observed (Fig. 3d,e). Velocity maps appear smoothed and do not demonstrate regions with strong in or outflow as typically seen in terminus aneurysms [6].

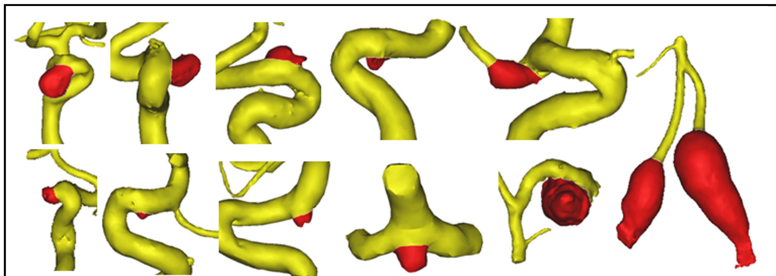

Fig. 1. Surface renderings of the 12 aneurysms (colored in red).

Discussion and Conclusions: We conclude that 4D cardiac gated PC SOS is a well suited approach to study flow and pathological conditions in and around intracranial aneurysms. We have found that the improved spatial resolution enables characterization of regions with complex flow in small vascular structures. By better visualizing the regions of high inflow, as in Fig. 3c, the improved spatial resolution could prove useful in the diagnosis, monitoring of disease progression, and monitoring surgical treatment of aneurysms. For example, the inability to visualize the regions of high-inflow in the low resolution reconstructions of Fig. 3e could incorrectly suggest successful treatment in post-op exams. In addition, the high spatial resolution data are well suited to derive hemodynamic parameters such as pressure gradients and wall shear stress.

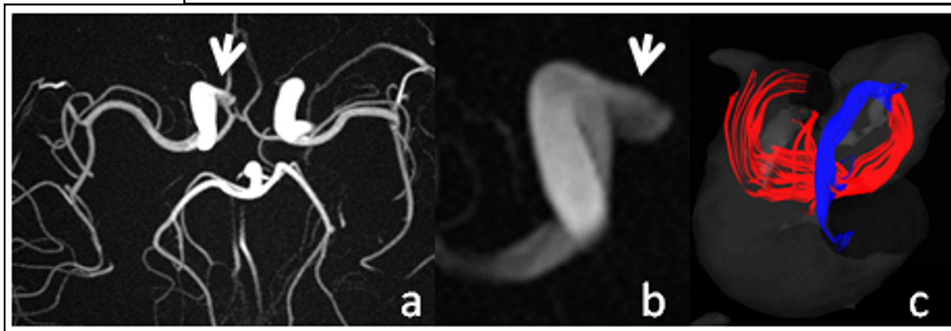

Fig. 2. Example images of a 3.8 mm aneurysm (arrow) in the right carotid artery demonstrating the fine vessel conspicuity, high spatial resolution, and superior background suppression of PC SOS (a/b) Full/limited axial MIPs from PC SOS angiogram. Streamlines (c) depicting **inflow**/**outflow** colored with **blue**/**red** to illustrate the 3D circulation pattern within the aneurysm.

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References [1] Hoi *et. Al*, JNS, 2004 [2] Shojima et *et. Al*, Stroke, [3] Kecskemeti *et. Al* Proc 17th ISMRM('08) 2907, [4] Johnson et. *Al* MRM 63:349-355(2010). [5] Barger et. *Al* MRM 48:297-305(2002) [6] Mantha *et. Al*, J. Biomechanics 42 1081-1087 (2009).

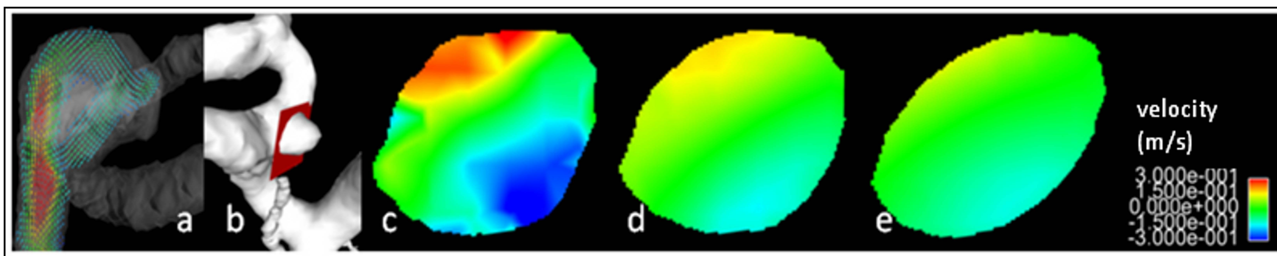

Fig. 3. Velocity vectors in a 2.3mm aneurysm in the carotid terminus a.) show higher velocity blood traveling up from the left internal carotid artery, circulating around the aneurysm, and finally entering the left anterior cerebrbral and left communicating artery. b.) Anatomical view of placement of plane used in (c/d). c.) Flow into and out of the aneurysm through the plane in (b), showing a nice delineation between high flow entering the aneurysm (red) and that leaving (blue). d/e.) The same dataset, reduced to resolution of 1.0x1.0x1.0mm and 1.5x1.5x1.5mm does depict as well the high speed entering and low speed exiting the aneurysm.