Flow Dynamics in an In Vitro Aneurysm Model at 1.5 and 3.0 Tesla

J. W. Grinstead[1], S. Sinha[1], S. Tateshima[1], Y-L. Nien[1], F. Vinuela[1]
[1]University of California, Los Angeles, Los Angeles, CA, United States

Introduction

MR angiography using phase-contrast flow quantification (PC-FQ) is able to measure the 3D velocity distribution of blood over the cardiac cycle noninvasively. Recent hardware and software advances (e.g., active gradient shielding and concomitant gradient reduction) allow improvements in the accuracy and resolution of PC-FQ. Because it is desirable to visualize the magnitude and direction of the velocity over the cardiac cycle, a robust, multi-platform, and extensible software was developed to process PC-FQ data, and is applied here to an in vitro aneurysm model.

Materials and Methods

In vitro data was acquired using a geometrically realistic acrylic basilar tip aneurysm phantom manufactured at 2.6X actual size (aneurysm measured 10.1x9.1 mm, neck diameter 8.4 mm) previously used in laser Doppler velocimetry [1]. It was connected to a pump with a programmed basilar artery waveform. The R-R interval and maximum velocity were set to give the same Reynolds number for the larger *in vitro* phantom as expected *in vivo*. A triggered 2D FLASH PC-FQ sequence with 3D flow encoding was used. Scan parameters on a 1.5T Siemens Symphony were TR/TE/FA = 99/9.8/20°; v_{enc}= 22 cm/s; BW = 110 Hz/pixel; 210x118 mm FOV; 256x144 matrix; slice thickness = 2mm; 21 cine frames; 4 averages; 9 min scan time. Scanning on a 3T Siemens Trio were TR/TE/FA = 100/5.3/30, 2 averages, 320x320 matrix, 140x140 mm FOV, 280 Hz/pixel, 20 frames, 1 segment, 6.5 min scan time.

Images were taken offline to a PC and sorted using fields from the DICOM header. The phase-image grayscale values were converted to velocity and imported into Matlab (Mathworks, Natick, MA). This software environment was chosen because it is widely available on a number of platforms, can be compiled to run on systems without Matlab, and easily allows the integration of other image processing tools, such as denoising or segmentation packages. The thru-plane velocity data was plotted as contour maps colored with blue and red representing opposite flow direction. In-plane velocity data could be displayed as vector field maps where the arrow length is proportional to the velocity magnitude.

Particle tracking was performed to visualize the blood flow. Starting with an initial particle location at a given time, the time-varying in-plane velocity data is used to calculate the position the particle would be at a subsequent time point, and is continued until the end of the cardiac cycle. Path calculation was stopped if it moved outside the vessel of interest, outlined manually. Motion was assumed to be restricted to the plane of the image, but an option allowed termination of a streamline if it left the slice by taking into account the thru-plane velocity. Given multiple slice data, one could track the particles over the entire 3D volume as shown by others [2]. Path seed points could be chosen manually or spaced evenly over a user defined range. Average calculation and display time was ~0.25 sec/seed point. Any combination of these plots can be displayed and shown as a cine, and animations of the particle path can be viewed. Regions of interest can be selected and the velocity in any direction can be plotted over the cardiac cycle.

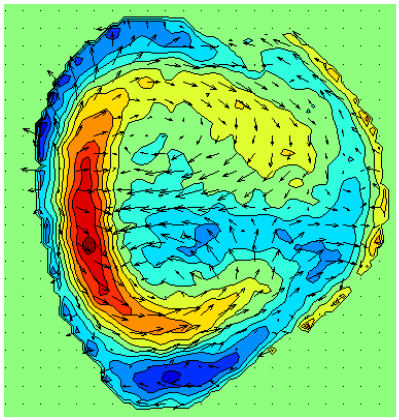
fig.1

Results

An axial slice thru the dome of the aneurysm is shown in **Fig.1**, with the in-plane vector field superimposed onto the thru-plane contour map. It shows twin vortices adjacent to the boundary layer of inward and outward flow, and retrograde flow near the location of the bleb (a localized outpouching of the aneurysm dome, blue region at the bottom of the figure). Viewing the data as a cine showed that the vortices did not change location significantly over the cardiac cycle despite significant changes in thru-plane velocity, as was seen in a previous Laser Doppler Velocimetry experiment [1]. This difference may be due to slice-thickness averaging. The paths generated by the particle tracking algorithm for an adjacent axial slice are shown in blue in **Fig 2**. The purple dots are the positions of the particles at a single time frame in the overall cine animation. The paths are seen to preferentially merge toward the upper vortex. The particle paths are superimposed directly onto the thru-plane phase-contrast image in **Fig. 3**, where it appeared that greater details of intra-aneurysmal flow information were obtained with the increased spatial resolution at 3T.

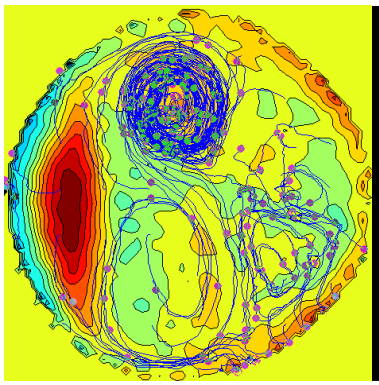
fig.2

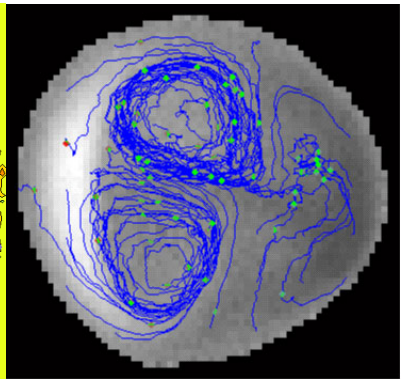
fig.3

Conclusions

The phase contrast technique successfully depicted the complex intra-aneurysmal flow structures in the in vitro aneurysm model. The long-term objective of this work is to test the feasibility of PC-FQ techniques and subsequent image processing tools in the development of routine methods to quantify complex blood flow dynamics over the cardiac cycle, primarily within intracranial vasculature. Previous in vivo data from an arteriovenous malformation has also been processed with the improved software [3].

References

[1] Tateshima S, J Neurosurg, 2001, 95(6): 1020-7 [2] Buonocore M, MRM, 1998, 40(2):210-26 [3] Grinstead J, ISMRM 2003, #100.