Differences in MR-Based Predictions of Steady and Pulsatile Flow Phenomena in Aneurysms

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Introduction

High resolution volumetric imaging (e.g. MRA or 3D DSA) is widely used to produce 3D rendered views for morphologic assessment of vascular pathology. While phase contrast (PC) velocity mapping in general is too time consuming to provide volumetric velocity maps of the cranial circulation, it is realistic to generate a single plane of time-resolved velocity data during patient scanning. In combination with angiographic data, Steinman and others (1,2) have shown it is feasible to recast hemodynamic characterization of vascular segments as a computational fluid dynamics (CFD) task by providing such patient specific inlet and boundary conditions. We examine the impact of different approximations to the true hemodynamic inlet boundary conditions on the resulting hemodynamic models in the context of intracranial aneurysms.

Materials and Methods

6 patients with large or giant intracranial aneurysms (2 MCA, 2 BasA, 1AComm, 1 fusiform VertA) underwent 3D ToF MRA (TE / TR / FlAng / SLT 3.5ms / 33ms / 18º / 1mm, FOV / Matrix / #SL 18-19cm / 320x512 / 64-80) and 2D time-resolved PC velocity mapping (TE/TR/FlAng/SLT 12ms / 22ms / 12º / 5mm, FOV / Matrix / NEX 16cm / 320x512 / 4) 2 – 6 cm proximal to the aneurysm on a 3T scanner (Intera, Philips Medical Systems). Data were transfered offline in DICOM format. The 3D MRA were segmented with a combination of region-growing and manual editing (Amira 2.3, TGS) to identify the vessel boundaries. A surface mesh and volume grid for the resulting boundaries were generated using Amira and Gambit (Fluent Inc.). The cross-sectional average velocity waveform was extracted from a region of interest closely matching the feeding vessel on the phase contrast velocity map. The time-average and temporal maximum velocity were used to define a steady flow and offset sinusoidal waveform having the same net flow as the measured waveform. Simulations based on the computational model aneurysmal geometry and each of the three inlet velocity waveforms were carried-out using CFDRC. From the simulations, snapshots of the velocity patterns and maps of the corresponding pressure, wall shear stress, and voriticity were generated at timepoints throughout the cardiac cycle.

Results

Visual inspection of simulated blood flow gives a strong impression of the residence time for blood in the aneurysm as well as an understanding of the flow pattern near the orifice of the aneurysm (Fig 1) by depicting the “unsteady” streamlines (lines where the blood velocity vector is tagent). Secondary motion patterns, are strongly influenced by the choice of inlet condition. As compared to the simulations based on the realistic flow, the steady flow model was generally preferable to the offset-sinusoid in respect to the flow topology produced. The temporal changes in hemodynamic parameters could not be appreciated in the steady flow simulations, but the pattern and peak values of parameters such as vorticity and shear stress were not well approximated by the offset-sinusoid, with some features appearing in these simulations were not present to the realistic flow calculations.

Conclusions

Steady flow simulations are typically some 20x faster to produce than those for unsteady inlet boundary conditions. In the clinical setting, the topological information available from faster steady flow simulations may be useful, but accurate modeling of spatial and temporal changes of the shear stress on the arterial surface, which are crucial factors for the endothelium function requires patient-specific pulsatile flow conditions as obtained from phase contrast velocity mapping are necessary for generating accurate hemodynamic models.

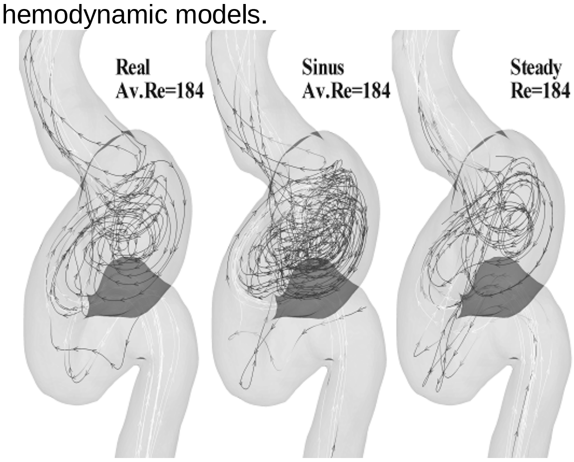

Figure 1: Derived “unsteady” streamlines in a fusiform aneurysm at a time point of equivalent Reynold’s number during the cardiac cycle for realistic (left), offset sinusoidal (center) and steady (right) inlet conditions.

References

1 Steinman et al .
AJNR 2003;24:559-66
2 Papathanasopoulou et al.
JMRI 2003;17;153-62