Loss of hemodynamic information in intracranial aneurysms: phase contrast MRI in a real-size phantom at different spatial resolutions

P. van Ooij[1,2], A. Guédon[1,2], J. Schneiders[1], M. C. Rutten[3], H. Marquering[1,2], C. B. Majoie[1], E. vanBavel[2], and A. J. Nederveen[1]
[1]Radiology, Academic Medical Center, Amsterdam, Netherlands, [2]Biomedical Engineering & Physics, Academic Medical Center, Amsterdam, Netherlands,
[3]Biomedical Engineering, Eindhoven University of Technology, Eindhoven, Netherlands

Purpose/Introduction: It is believed that hemodynamic properties of blood flow in intracranial aneurysms, such as vortical flow and wall shear stress, contribute significantly to aneurysm rupture risk assessment. These properties can be deducted from three-dimensional phase contrast MRI [1] (PC-MRI) measurements. In clinical practice PC-MRI is usually performed at resolutions of approximately 1 mm^3 because of scan time limitations. However, in small structures such as intracranial aneurysms, even higher resolution PC-MRI may be necessary to fully capture the hemodynamic properties. Accurate wall shear stress assessment in particular remains problematic since velocity gradients at the wall are needed for this calculation [2]. In this study PC-MRI measurements in a real-size intracranial aneurysm are performed at different spatial resolutions to study the loss of flow information when performing PC-MRI at relatively low resolutions.

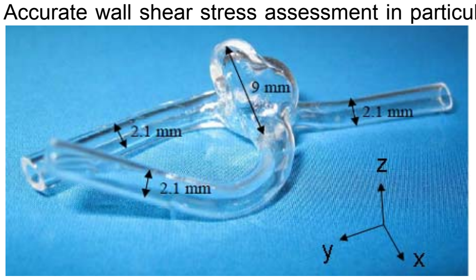
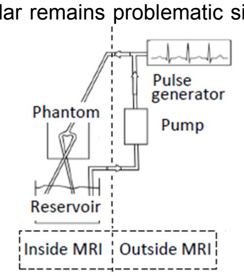


Fig 1a. Aneurysm phantom



b. Experimental set-up

Materials & Methods: A glass reproduction of a high-resolution 3D Rotational Angiograph of an aneurysm located in the anterior communicating artery of a patient who supplied informed consent was manually created and connected to a pump. The phantom with an inner size of 6x4x9 mm (length, width, height, no up-scaling) is shown in figure 1a; the experimental setup is shown in figure 1b. A steady (application of constant flow, no gating) PC-MRI measurement was performed on a 3T MR system (Philips Medical System, Best, The Netherlands) in a solenoid rat coil with a diameter of 7 cm at isotropic resolutions starting at 0.3 mm to 1 mm with steps of 0.1 mm. TE/TR = 4.28/8.66 ms (0.3 mm resolution), flip angle: 15°, velocity encoding: 50x100x50 cm/s in the x, y and z direction (see figure 1a) respectively. To minimize noise the data was filtered with a 3D median filter (kernel size: 3x3x3 pixels). Differences between velocity vector angles were determined for voxels where the velocity magnitude was higher than 20% of the maximum velocity magnitude to reduce discrepancies due to the lower SNR for small velocities. All interpolations were cubic.

Results: In figure 2a and b flow patterns are shown in a sagittal cross-section through the phantom at 0.3 mm and 0.8 mm interpolated to 0.3 mm respectively. In figure 2c the non-interpolated measurement at 0.8 mm is displayed. Figure 3 displays the standard deviation of the paired difference (SDpaired) and the median angle in every voxel between the lower resolutions and 0.3 mm resolution. In figure 4a the velocity profile in y-direction (see figure 1a) is given along arrow 1 as displayed in figure 2a with enlarged velocity gradients at the wall A and B. In figure 3b the velocity profile in x-direction is given along arrow 2 with enlarged gradients at the wall C and D.

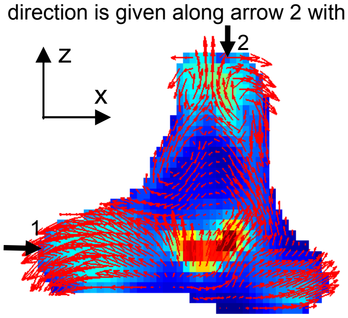
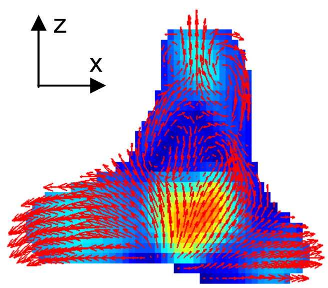
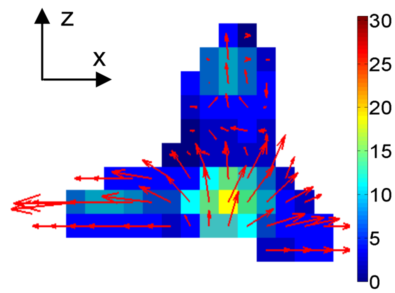


Fig 2a. Velocity vectors and magnitude at 0.3 mm



b. Velocity vectors and magnitude at 0.8 mm interpolated to 0.3 mm



c. Original velocity vectors and magnitude at 0.8 mm

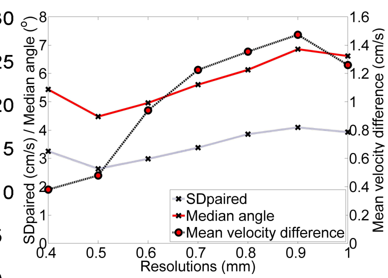


Fig 3. Difference properties between the measurements and 0.3mm

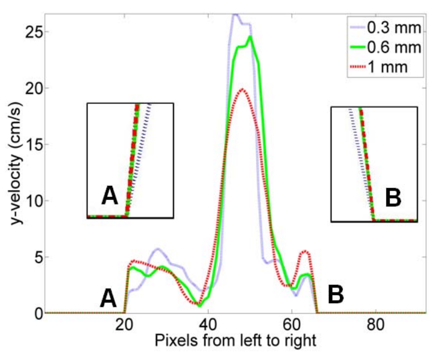
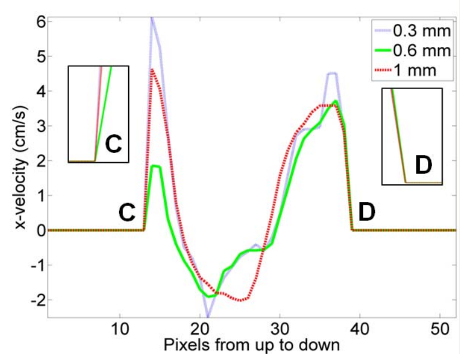


Fig 4a. Y-velocity profile at arrow 1 with enlarged velocity gradients A and B at the wall



b. X-velocity profile at arrow 2 with enlarged velocity gradients C and D at the wall

Table 1: Gradients at wall (s^{-1})

	0.3 mm	0.6 mm	1 mm
A ($\partial v_y/\partial x$)	7.0	14.2	15.4
B ($\partial v_y/\partial x$)	6.0	10.5	11.2
C ($\partial v_x/\partial z$)	22.7	6.9	17.2
D ($\partial v_x/\partial z$)	10.1	11.3	10.5

Discussion: The main difference between figures 2a and b is the lower maximum velocity and the smoothed flow features at 0.8 mm. However, the number of vortices is equal and locations of the vortices are similar. This is remarkable when figure 2c is considered, where a small amount of flow vectors is obtained that can still yield detailed flow features in figure 2b after interpolation. From figure 3 it is clear that differences between 0.3 mm and the other measurements increase at lower resolutions. In figure 4a the y-velocity gradients at the wall are emphasized and both A and B show a difference in the velocity gradient at the wall for 0.6 and 1 mm resolution of about two times with 0.3 mm (table 1). The x-velocity gradient at the wall at C of 0.6 mm is even 3 times lower than 0.3 mm whereas the gradient at the wall of 1 mm is closer to the value of 0.3 mm. At D the differences between the gradients at the wall are small.

Conclusion: Qualitatively, to capture the complex flow features such as vortices and inflow jet locations in intracranial aneurysms, low resolutions such as 1 mm isotropic may well be sufficient. It is important to realize, however, that the flow patterns are measured with more detail at higher resolutions. Quantitatively, high velocities are missed at low resolutions and mean velocities will differ slightly as well as flow directions. Small and large differences can both be found in velocity gradients at the wall, resulting in unreliable wall shear stress estimations in intracranial aneurysms.

References:

[1] Markl et al.JMRI, 17(45): 499-506 (2006)
[2] Boussel et al. MRM 61(2):409-417 (2009)