

Complex flow patterns in a real-size intracranial aneurysm phantom: a PC-MRI study compared with PIV

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Purpose/Introduction: Blood flow velocity measurements using '7D' Phase Contrast MRI (PC-MRI) have been extensively validated in literature in structures such as the aortic arch^[1] or the carotid arteries^[2]. However, in small structures such as cerebral arteries^[3] or intracranial aneurysms^[4], accurate velocity measurements are more challenging due to higher resolution demands, intravoxel dephasing in complex flow and decreased velocity to noise ratio (VNR) or increased velocity aliasing as a result of velocity encoding (Venc) choices. In this study PC-MRI velocity measurements are performed in a glass phantom of an intracranial aneurysm and the results are compared with Particle Image Velocimetry (PIV) measurements.

Materials & Methods: A glass reproduction of a high-resolution 3D Rotational Angiography measurement of an aneurysm located in the anterior communicating artery of a patient was manually created and connected to a pump and a pulse generator. Informed consent was given. The phantom of inner size 6 x 4 x 9 mm (length, width, height, no up-scaling) is shown in figure 1; the experimental setup is shown in figure 2. A measurement with steady and a measurement with pulsatile flow conditions was performed. MRI measurements were performed on a 3T MR system (Philips Medical System, Best, The Netherlands). MRI: voxel size: 0.5 x 0.5 x 0.5 mm³, TE/TR: 3.1/6.4 ms, flip angle: 15°, NSA: 2, Venc (x,y,z) : 100, 200, 100 cm/s, SENSE factor: 3, pulsatile cardiac phases: 19, pump frequency: 1 Hz, fluid: water, surrounding environment: agar gel. Input mean velocity steady/pulsatile: 40/50 cm/s. Scan time: 69 minutes. PIV: voxel size: 0.33 x 0.33 x 0.25 mm³, pulsatile cardiac phases: 19, pump frequency: 1 Hz, PIV fluid: a solution of 1075 g/L NaI in 60% water and 40% glycerol with spherocells and sodium thiosulfate, surrounding environment: PIV fluid. Input mean velocity steady/pulsatile: 48/55 cm/s. The pulsatile input waveform previously measured with MRI in the patient's internal carotid artery is displayed in figure 5. The results of the PIV measurements, which consists of the x and y components in a z-stack of separate measurements of the flow velocity, were downsampled to the voxel size of the MRI measurement and compared with its x and y components.

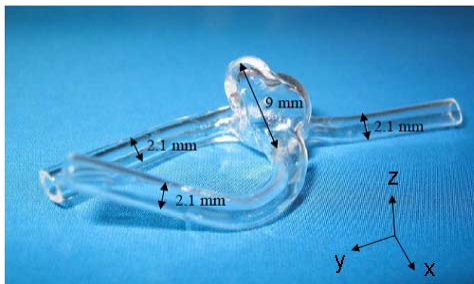


Fig 1. Aneurysm phantom

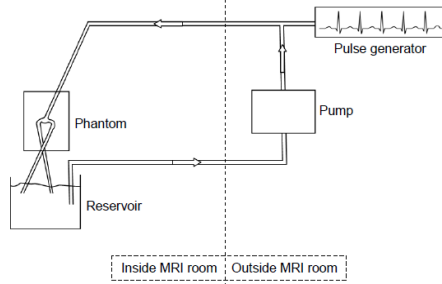


Fig 2. Experimental set-up

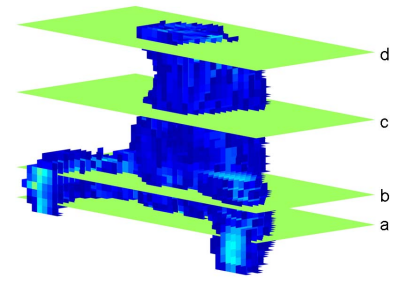


Fig 3. Non-interpolated steady PIV results with slices depicted in figure 4

Results: MRI measurements with the PIV fluid showed severe artifacts and no usable flow information could be extracted. Water was therefore used in MRI. In figure 4 the steady velocity magnitude (in cm/s) and direction are shown in four cross-sections through the phantom as displayed in figure 3. The velocity profiles of the pulsatile measurement were similar to the steady measurement and therefore not displayed. In table 1 the mean and the maximum velocity of the steady measurements and the mean velocity averaged over time and the maximum velocity of the pulsatile measurement are given. In figure 5 the mean velocity curves are shown for the pulsatile measurement.

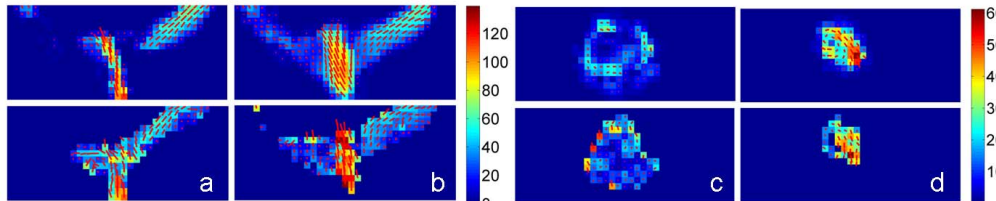


Fig 4. Velocity (cm/s) in four slices through the phantom for steady PIV (top) and steady MRI (bottom)

Measurement		Mean v (cm/s)	max v (cm/s)
PIV	steady	29	113
	pulsatile	19	175
MRI	steady	33	139
	pulsatile	38	211

Discussion/Conclusion: The mean velocity is higher for MRI than for PIV in both the steady and pulsatile measurement, shown in table 1 and figure 5. This is due to the use of water in MRI, which has a lower viscosity than the PIV fluid used in PIV. The influence of a lower viscosity may be larger in the pulsatile than in the steady measurement, as can be deduced from the results shown in table 1, where the difference of the mean and maximum velocity between MRI and PIV is higher in the pulsatile than in the steady measurement. From figure 4c it is clear that noise found in the MRI measurement causes complex flow profiles of low magnitude to be more difficult to measure in MRI than in PIV. A lower Venc may improve VNR and the accuracy of complex flow measurements, which is supported by figure 4d where a vortex of higher velocity is seen in both the PIV and MRI images. Furthermore, a more MR compatible material than glass, now used for PIV measurements, will further improve the results. Overall, these results show that it is possible to measure complex flow patterns with MRI but improvements in VNR, e.g. by more accurate choices of Venc, and improvements in scan time, e.g. by acceleration techniques, are needed to enhance diagnostic use of '7D' velocity scans in intracranial aneurysms.

References

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^[2] Harloff A et al. MRM 61:65-74 (2009)
^[3] Wetzel S et al. AJNR 28:433-38, Mar 2007
^[4] Boussel L et al. MRM 61:409-417 (2009)

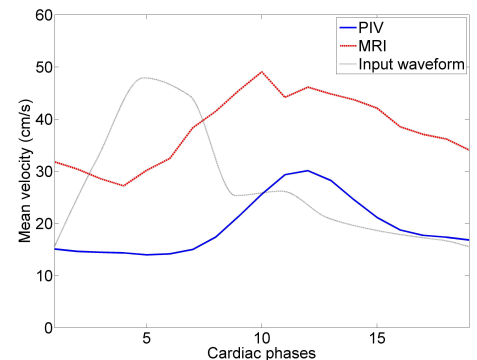


Fig 5. Mean velocities and input waveform