Comparison between 3D phase contrast MRI and Computational Fluid Dynamics in unruptured intracranial aneurysms.

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Purpose/Introduction

Hemodynamics are thought to play an important role in formation, growth and rupture of intracranial aneurysms. Visualisation of the hemodynamics in these relatively small structures is challenging. However, Computational fluid dynamics (CFD), a fluid-simulation technique, is increasingly used to visualize intra-aneurysmal flow patterns. Advantages of using CFD for visualization are its high resolution and the possibility to simulate complex flow in sub-centimeter structures. A drawback of this method is, that it requires invasive 3D rotational angiography (3DRA) data and patient specific 2D PC MR measurements of the inlet velocity as boundary condition.

With increasing MR field strength and advancing technique, we are now able to scan a 4D phase contrast volume of an intracranial aneurysm with enough resolution to describe flow patterns.[1] In this study we compare results of time averaged 4D MRI of the aneurysm and surrounding vessels with CFD simulations obtained from high resolution 3DRA and inflow 2D PC MR velocity measurements.

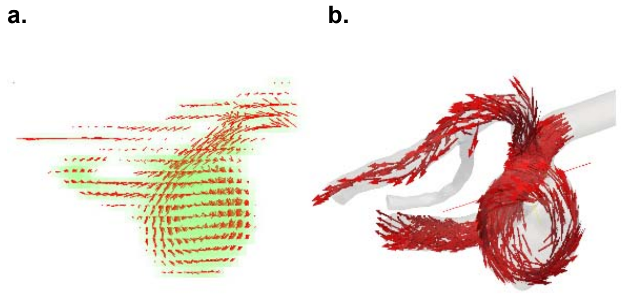
Materials & Methods

4 patients with 4 intracranial aneurysms were scanned using a 3T MR system (Philips Medical System, Best, The Netherlands). MR 4D phase contrast scan sequence parameters: voxel size: 0.8 x 0.8 x 0.8 mm^3, TE/TR:2.8/5.6 ms, flip angle: 15°, NSA: 2, Venc (x,y,z): 60-100 cm/s, SENSE factor: 3, 10 cardiac phases, retrospective cardiac gating. MR 2D phase contrast scan sequence parameters: 0.65 x 0.65 x 3.0 mm^3, TE/TR:2.8/5.6 ms, flip angle: 15°, NSA: 2, Venc (x,y,z): 70-100 cm/s, SENSE factor: 3, >36 cardiac phases, retrospective cardiac gating. All patients had the MR scan in the diagnostic workup following the detection of an intracranial aneurysm. The extra sequences extended the scan-time with 20-25 minutes, for the extended scan-time, informed consent was obtained.

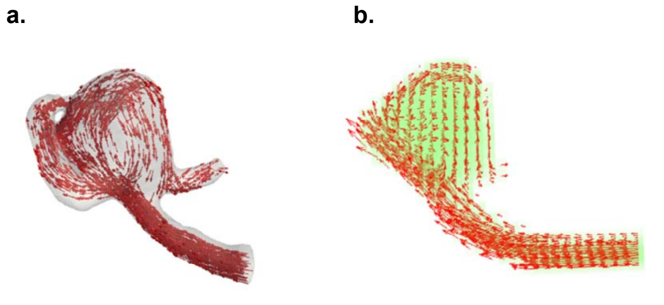
The Computational Fluid Dynamics simulation is build with a geometry segmented from a 3D rotational angiography which was performed during the diagnostic workup. Segmentation software (Vascular Modeling ToolKit)[2] provided geometries with 700.000 to 3 million tetrahedral elements. CFD simulations were calculated with Fluent ® software (ANSYS, Canonsburg, USA), boundaries were set to rigid walls, no-slip surface, Newtonian fluid, viscosity 0.004 kg/m s^1, fluid density 1000 kg/m^3. Inflow boundary was the mean flow velocity in the inflow vessel which was measured using a 2D MR phase contrast measurement in the aneurysm inflow vessel. MR results were recalculated to visualize a mean velocity from the entire cardiac cycle, so to best compare with the mean velocity inflow which was used in the CFD calculation. The patients' aneurysms were located in the anterior communicating artery, the middle cerebral artery and the carotid artery. The aneurysms' size ranged from 4 to 21 mm.

Results

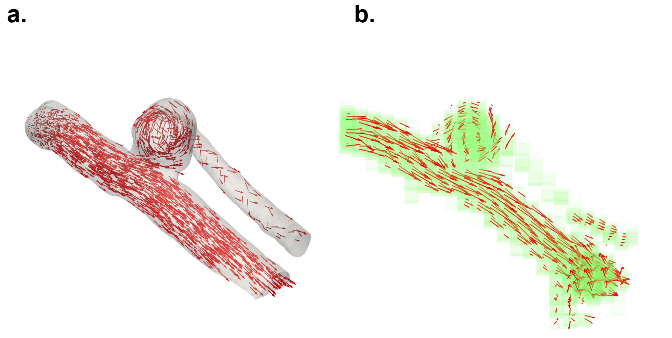
Below is a 2D depiction of flow characteristics in aneurysms, visualized in 3D using both PC-MR and CFD. The size of the aneurysm is given by the biggest measured diameter.



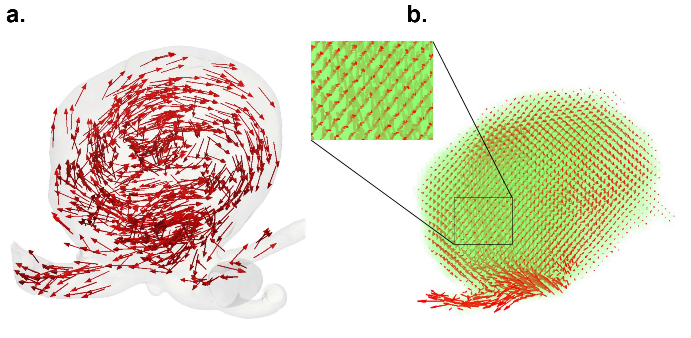
Case 1: (aneurysm size 9mm) a. MRI, b. CFD



Case 2: (aneurysm size 7mm) a. MRI, b. CFD



Case 3: (aneurysm size 4mm) a. MRI, b. CFD



Case 4: (aneurysm size 20mm) a. MRI, b. CFD

Conclusion / Discussion

Flow patterns obtained from 3D PC MRI at 3T are comparable with results of CFD simulations obtained from invasive 3DRA and 2D PC inlet velocity measurements. Advantage of PC-MRI over CFD is that with PC-MRI it is much easier to visualize pulsatile flow and wall motion. However, due to complex flow patterns occurring within one voxel, small vessels (<1,5 mm) and small aneurysms (<4mm) are difficult to measure with our sequence in patients. Higher resolution scans would decrease these disadvantages, but scan times will increase.

References

1) Boussel L et al. MRM 61:409-417 (2009)
2) Antiga L et al. MBEC 46(11):1097-112 (2008)