Temporal Stability of Blood Flow Patterns in Cerebral Aneurysms Quantified with 2D Phase Contrast Magnetic Resonance Imaging In-Vivo

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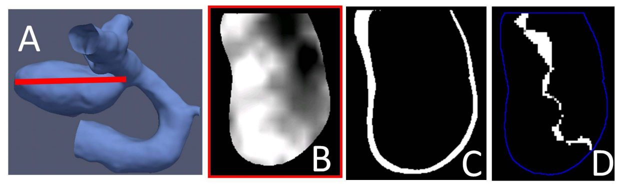
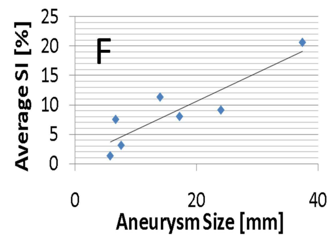
Introduction: Complex and unstable blood flow patterns in cerebral aneurysms have been identified by computational fluid dynamics (CFD) studies to potentially be predictive of aneurysm rupture [1, 2]. 2D Phase contrast magnetic resonance imaging (pcMRI) has previously been utilized for visualizing and quantifying intra-aneurysmal blood flow patterns (IFP) in vivo [3] in good agreement with CFD results [4, 5]. Here, we demonstrate the capability of quantifying the stability of blood flow patterns in cerebral aneurysms *in vivo* based on the analysis of flow features in 2D pcMRI slices intersecting the main flow patterns inside cerebral aneurysms.

Material and Methods: For each of seven intracranial aneurysms (one aneurysm of the anterior communicating artery (AComA), one basilar tip aneurysm (BA) and 5 aneurysms of the internal carotid artery (ICA)), IFPs were visualized by 2D pcMRI images acquired in two planes approximately perpendicular to each other intersecting the flow patterns inside the aneurysm dome. All images were acquired on a Siemens 1.5 T Sonata Magnetom MRI scanner (Siemens Healthcare, Erlangen, Germany). 2D pcMRI slices were positioned from a 3D surface reconstruction of a time-of-flight localizer by quantitative magnetic resonance (QMRA) software [6]. Dependent on the length of the cardiac cycle, 12 – 20 pcMRI images per cardiac cycle were obtained using a peripheral pulse monitor and a retrospective gating approach (FOV 160 mm, slice thickness 5 mm, matrix: 256 (frequency direction), 75 % (phase direction). Velocity-encoding (VENC) values were manually adjusted for optimal contrast and ranged from 60 to 150 cm/s, through-plane velocity encoding). Volumetric flow rates in the parent artery were determined with the same technique and a reference time with approximately half of maximum flow was determined. A stability index (SI) ranging from 0 for temporally stable IFPs to 1 for unstable, strongly varying IFPs was calculated for each IFP defined as the area fraction (in percent) exhibiting sign change of the through-plane velocity component relative to the reference time, using a mask to exclude aneurysm wall motion effects (figure 1, A-D). The average SI for each aneurysm was calculated as the average over all time points in the two planes. Average SI was compared to aneurysm size (maximum diameter).

Figure 1: A: 3D model of ICA aneurysm #3 showing location of one 2D pcMRI slice (red line) **B:** Two main flow features with opposite directional flow (lateral white and black areas) distinguishable in 2D pcMRI slice shown in A. **C:** Aneurysmal wall motion (white border) [7]. **D:** Blue outline: total area. White: Area changing sign of velocity (located along the border of the two main flow features). **E:** Aneurysm size and average SI **F:** linear relationship between both quantities (R=0.769).



E	*Average SI[%]*	*Aneurysm Size[mm]*
1. AComA, small bleb	*7.5*	*6.7*
2. BA, single lobe	*1.3*	*5.8*
3. ICA, single lobe	*3.1*	*7.6*
4. ICA, single lobe	*8.0*	*17.2*
5. ICA, double lobe	*9.1*	*24*
6. ICA, double lobe	*11.3*	*14*
7 .ICA, single lobe	*20.6*	*37.4*



Results: While small aneurysms (in particular AComA and BA) exhibited simple, relatively stable IFPs, flow in larger aneurysms was more complex (strong separating entry jet in largest ICA aneurysm (#7)). Average SI ranged from 1.3 % (BA) to 20.6% (largest ICA aneurysm #7, figure 1, E). A linear relationship between average SI and aneurysm size (largest diameter) was found, R=0.796, (figure 1, F)

Conclusion: 2D pcMRI can visualize and quantify temporal stability of blood flow patterns in cerebral aneurysms. The average stability index, defined as the fraction of the aneurysmal cross-sectional area that exhibits flow reversal during the cardiac cycle, was found to correlate linearly with aneurysm size (maximum diameter). Further studies are warranted to explore the potential of the average stability index as a marker for aneurysm rupture.

References:

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