In-vivo visualization and analysis of 3D hemodynamics in cerebral aneurysms with flow-sensitized 4D MR imaging at 3T

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Introduction: Intra-aneurismal flow and secondary-derived flow parameters, such as wall shear stress (WSS) are assumed to play a major role in development and rupture of cerebral aneurysms. To date, such flow patterns and the distribution of WSS inside a cerebral aneurysm have been extensively studied *in-vitro* using geometric realistic aneurysm models [1]. The purpose of this study was to evaluate the feasibility of *in-vivo* flow-sensitized 4D MR imaging for the visualization and quantification of intra-aneurismal hemodynamics.

Materials and methods: 5 cerebral aneurysms, differing in size, shape and location, were examined in 3 patients. Flow-sensitized 4D MR imaging was composed of an RF-spoiled flow-sensitive time-resolved 3D gradient echo sequence with prospective cardiac triggering which was applied on a 3T scanner (Allegra, Siemens, Germany). Scan parameters: VENC: 90cm/s, flip angle=15°, TR/TE=6.8–7.0/4.0–4.4 ms, temporal resolution=44.8 ms, rectangular FOV [220x165–183 mm^2], 24–32 sections/slab, spatial resolution=1.0x0.7x1.2 mm^3 [2]. Postprocessing using a commercial 3D visualization software (EnSight, CEI, USA) included time-resolved 2D vector graphs and time-resolved 3D particle traces, and visualization of vortex core segments [3]. For estimation of intra-aneurismal WSS, 3D velocity data was extracted from interactively positioned 2D analysis planes (2mm distances) and exported into an in-house software tool based on Matlab [4]. After frame-wise interactive aneurismal lumen segmentation, vectorial WSS (axial and circumferential components) were derived from the deformation tensor of the measured 3D velocity field. Temporally averaged magnitude of WSS was extracted along the segmented aneurismal walls (Fig 1). Local WSS magnitudes were represented as percentage of the spatio-temporally averaged WSS magnitude measured in the upstream parent artery. All flow patterns and WSS estimations were analyzed in relation to aneurysm geometry and aspect ratio (aneurysm depth/neck width).

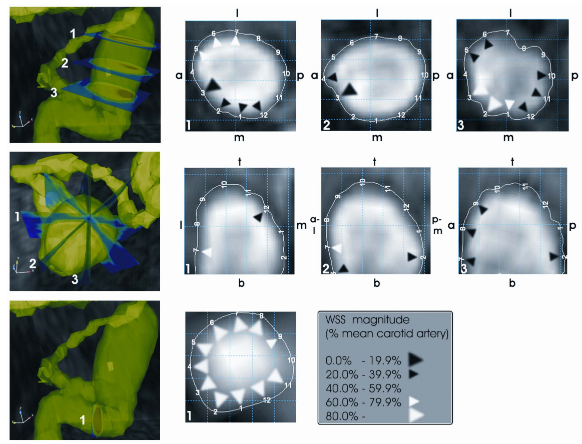

Fig 1. Distribution of WSS inside parophthalmic internal carotid artery (ICA) aneurysm. Aneurismal walls are segmented on 2D planes (white lines). Temporally averaged relative WSS (***black and white arrowheads)*** estimated for 12 clockwise positions (***small numbers 1-12***). *Top pane and mid panel:* High WSS adjacent to inflow stream. Heterogenous low WSS at mid sac and dome level. *Lower panel*: High WSS along whole circumference of the upstream ICA.

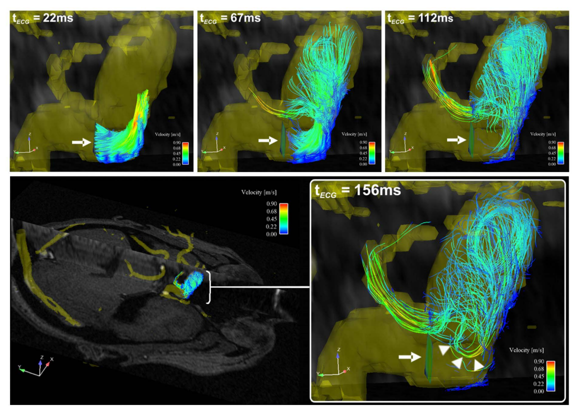

Fig 2. Time-resolved 3D particle traces in 4 consecutive systolic timeframes in large parophthalmic internal carotid artery (ICA) aneurysm. Color coding corresponds to local flow velocity magnitude. Particle traces are released from emitter plane in upstream ICA (***white arrow***). Between high velocity inflow and outflow streams, a small vortex recirculates into aneurysm neck (***arrowheads***).

Results: Vortical blood-flow was the predominating pattern inside all aneurysms. The configuration, strength, and location of these vortices differed considerably among all aneurysms. Distinct inflow and outflow zones were distinguishable in all aneurysms except for the smallest aneurysm (2mm). Particularly spatio-temporally unstable vortical flow was demonstrated in a wide-necked parophthalmic internal carotid artery (ICA) aneurysm (high aspect ratio, Fig 2). Relatively stable vortical flow was observed in aneurysms with lower aspect ratio. Except for a wide-necked cavernous ICA aneurysm (low aspect ratio), WSS inside the aneurismal sac was reduced relative to the parent artery and showed a high spatial variation (10.0-78.4%, Fig 1).

Discussion and conclusion*:* *In-vivo* flow-sensitized 4D MR imaging can be applied to visualize aneurismal blood flow patterns, and to estimate WSS from 3D velocity fields inside cerebral aneurysms. Flow patterns and distribution of WSS seem to be determined by the vascular geometry of the aneurysm. The preliminary *in-vivo* results in a small number of different aneurysms confirmed those of recent *in-vitro* studies with aneurysm models.

Reference: [1] Shojima M et al., Stroke. 2004;35:2500-2505; [2] Wetzel S et al., AJNR, 2007;28:433-438; [3] Buonocore MH. MRM 1998;40:210-226; [4] Stalder AF. et al. , ISMRM, 2007: p3139