Quantification of 3D hemodynamics in large and giant intracranial aneurysms

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INTRODUCTION: Cerebral aneurysms are diverse and life threatening conditions. They typically develop at the major bifurcation sites of the intracranial vessels. In general, increasing size has been linked to higher rupture risk but specific data concerning which lesions will grow or destabilize is lacking. In this study seven patients with large or giant cerebral aneurysms were examined with 4D-Flow MRI and analyzed regarding 3D flow patterns (vorticity) and aneurysm wall shear stress (WSS). Two distinct groups of aneurysms were identified with fast swirling flow versus slow flow and significantly different WSS and vorticity patterns, correlating with aneurysm morphology.

METHODS: Seven patients (4 females, 3 males, mean age 53.6 ±15.4) with large or giant cerebral aneurysms (mean largest dimension = 2.5 +/- 0.9, range = 1.4 – 4.2 mm) were studied. Aneurysms were located near the ICA bifurcation (n=5) with a saccular/spherical morphology or the basilar artery (n=2) with a fusiform morphology and examined using 4D flow MRI (3T TRIO & 1.5T Avanto, Siemens, Germany, spatial resolution = 0.99-1.8 mm x 0.78-1.46 mm x 1.2-1.4 mm,TE/TR= 2.9-3.3 ms/5.5-6 ms, temporal resolution = 44-48 ms, 3-directional velocity encoding with venc = 70-80 cm/s). Data were analyzed with in-house Matlab-based tools (The Mathworks, USA) [1] and 3D blood flow visualization software [2]. Intra aneurysmal flow was visualized using time-resolved pathlines (Figure 1) and vector graphs mapped onto a 2D plane through the center of the aneurysm (Figure 2). The WSS pattern along the aneurysm wall was calculated by cubic spline interpolation of the velocity gradient along the aneurysm contour as described previously [3]. The vorticity defined as $Vort=\mathrm{abs}(\zeta_x,\zeta_y,\zeta_z)$ (with $\zeta_x = \delta w/\delta y - \delta v/\delta z$, $\zeta_y = \delta u/\delta z - \delta w/\delta x$, $\zeta_z = \delta v/\delta x - \delta u/\delta y$ and u,v,w being the vector components of the velocity [2]) was calculated for 48x48 points within the plane transecting the aneurysm. The vorticity was denoised with a 3x3 2D median filter for all cardiac phases, outliers were rejected.

RESULTS: The combination of 3D spatial encoding and 3-directional velocity encoding allowed for the 3D visualization of complex intracranial flow patterns (Figure 1). All aneurysms could be well segmented using the velocity data combined with magnitude data as shown in Figure 2. Flow patterns in the seven aneurysms could be classified in two morphological groups: Narrow high-flow channels along the aneurysm wall in combination with large central low flow regions were identified in saccular/spherical aneurysms of the anterior circulation (ICA or MCA, group 1, n=5). In contrast, slow flow with less defined flow channels were noted in fusiform aneurysms (VA or BA, group 2, n=2) (Figure 1, F and G). The distribution of WSS along the aneurysm wall (white lines, Figure 2) was significantly more heterogeneous and increased for group 1 compared to group 2(WSS =0.63N/m^2 ± 0.33N/m^2 vs. 0.038N/m^2 ± 0.016). Vorticity in the plane through the center of the aneurysm was significantly higher for group 1 versus group 2 (0.073 ± 0.028 vs 0.018 ± 0.005, Wilcoxon signed rank test, p < 0.01).

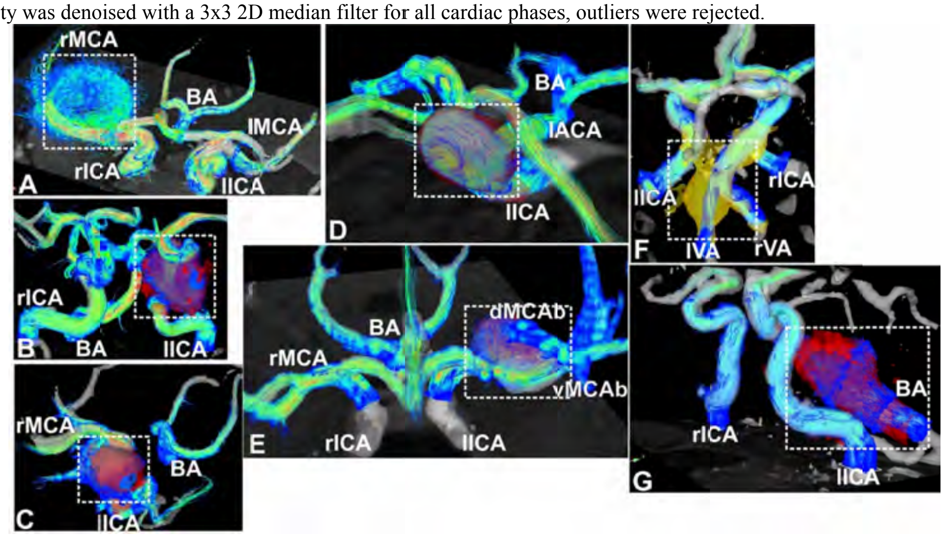

Figure 1: Intracranial aneurysms of group 1 (A – E) located at segment C7 of ICA or M1 of MCA showing fast flow with clear flow channels and group 2 (F and G, fusiform aneurysms) with slow and swirling flow located at the junction of the vertebral arteries or in the basilar artery. The white boxes indicate the location of the aneurysms.

DISCUSSION AND OUTLOOK: The findings of this feasibility study show the potential of 4D flow MRI to identified differences in flow characteristics such as vorticity and WSS patterns in two intracranial aneurysm morphology groups. Future longitudinal studies based on the measurement, analysis and visualization of intracranial aneurysm hemodynamics using 4D-Flow MRI have the potential to correlate disease progression with regional hemodynamics and may thus improve risk stratification and treatment planning.

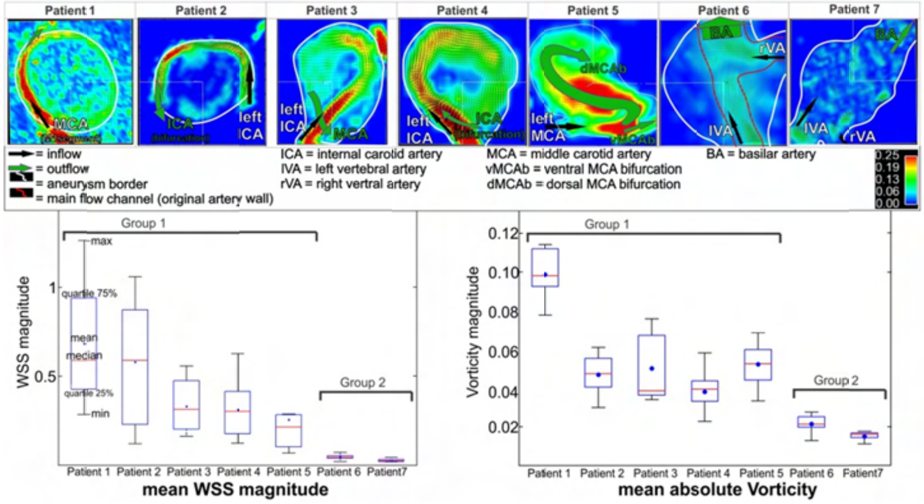

Figure 2: Analysis of WSS (left boxplot) and vorticity (right boxplot) in an exemplary plane through the aneurysm. WSS was analyzed for 12 equally distributed points along the border of the outlined plane through the aneurysm. The absolute vorticity was averaged in each plane (after median filtering and outlier rejection). Both were averaged over all cardiac cycles. The top row shows the chosen cut-planes through the aneurysms. A paired t-test showed that group 1 and group 2 have different means in WSS and vorticity, meaning they are drawn from different distributions.

REFERENCES: [1] Bock et al., Proc ISMRM 2007; [2] ENSIGHT, CEI, USA [3]; Stalder et al., MRM2007

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