Multimodal imaging of flow dynamics in a realistic aneurysm phantom

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Introduction: An aneurysm is the pathological enlargement of a blood vessel, with rupture and treatment complications posing significant risks due to potential life-threatening bleeding [1]. Blood flow dynamics are crucial for aneurysm formation and rupture risk assessment [2]. This study compares flow dynamics in realistic aneurysm phantoms using 4D flow MRI [3], Magnetic Particle Imaging (MPI) [4], and Optical Transmission (OT) [5] and investigates the impact of various artificial aneurysm curvatures.

Methods: The aneurysm phantom was created as follows: starting from anatomical CT or MRI data, the desired structure was extracted, converted into a 3D model, and prepared for SLA printing using flexible resin. The phantom was placed in the center of the scanner and connected with pipes to the pump. The flow dynamics were determined using three different imaging modalities: 4D flow MRI [8] enables accurate measurements of 3D flow fields but requires long scan times. OT offers direct flow visualization of food color bolus but requires translucent samples and an opacity-inducing tracer. MPI enables real-time imaging of a magnetic nanoparticle bolus without background signal.

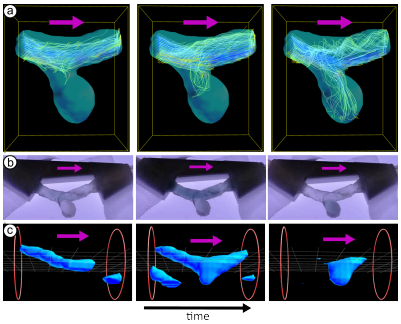

Fig. 1: Flow dynamics visualization in realistic aneurysm phantom with (a) 4D flow MRI, (b) OT and (c) MPI.

Results: The flow dynamics of a realistic aneurysm phantom were measured with 4D flow MRI, OT and MPI. The streamline visualization of the flow dynamics measured with 4D flow MRI is shown in Fig.1a. The bolus visualization for food color (OT) (Fig.1b) and Perimag® (MPI) (Fig.1c) show that bolus initially passes the aneurysm and then swirls partly into the aneurysm head, where it remains longer. Investigating the influence of vessel curvature on flow dynamics with MPI revealed significant influence on the flow dynamics inside the aneurysm head (Fig.2). The same was observed using 4D flow MRI.

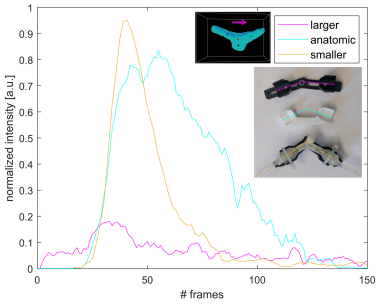

Fig. 2: Intensity tracked over time at the aneurysm head (see black point) for different aneurysm angles: larger than anatomic (pink), anatomic (blue) and smaller than anatomic (yellow).

Discussion and Conclusion: The measured flow dynamics showed good agreement and provided complementary information on the flow field and tracer distribution. Since the curvature of the aneurysm vessel was found to strongly influence the flow dynamics, further characterization of the aneurysm geometry must be performed.

References: [1] DeLuca et al., Neurovascular Neuropsychology, Springer (2020), [2] Neupane, et al. , J. Surgery (2022), [3] Markl et al. , J Magn Reson Imaging (2012), [4] Gleich, Weizenecker , Nature, (2005), [5] Adrian, Annual Review of Fluid (1993), [6] Reichl et al., Int J Mag Part Imag. (2022), [7] Guggenberger et al., J Magn Reson Imaging. (2021), [8] Schnell et al., J Magn Reson Imaging. (2017).