Hemodynamics in a cerebral aneurysm model treated with different flow diverting stent configurations: Assessment using highly accelerated dual-velocity encoded 3D phase-contrast MRI

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Introduction: Intracranial aneurysms remain a life threatening disease[1] and the assessment of rupture risk is commonly based on empirical and systemic parameters[2] such as hypertension, age, aneurysm morphology and location. It is well known, however, that hemodynamic parameters such as flow characteristics, wall shear stress, and pressure distribution play a crucial role in the growth and rupture risk of such aneurysms[3]. Devices that alter flow within the aneurysm sac in order to promote thrombus formation while keeping side branches and perforating arteries patent have recently emerged as an alternative to common coiling procedures. Due to their novelty and sophisticated mesh characteristics, the post-procedural course of the treated aneurysms is not fully predictable. Time-resolved 3D phase-contrast MRI has emerged as a technique to non-invasively assess flow in aneurysms in-vivo[4] and in-vitro[5]. Its intrinsic long scan time and limited sensitivity to low velocities however hamper the technique's routine application in clinical practice[6]. In the present work, a highly undersampled dual-venc acquisition scheme is used to acquire time-resolved 3D flow fields in aneurysm models deployed with different flow diverting stents. The technique's advantages compared to a single-venc acquisition is shown and flow characteristics are analyzed and compared to the native, unstented model.

Methods: Based on in-vivo 3D digital subtraction angiography data, a silicon model (Fig. 1) was duplicated five times: one model was left unstented (native), three models were stented using a flow diverting stent with 4mm, 5mm, and 6mm diameter respectively. One model was stented by overlaying two 4mm flow diverting devices (double-stenting). The models were connected to a pulsatile flow pump and MRI measurements were performed on a 3T system (Philips, Best, the Netherlands) using an 8 channel head coil. Flow data was acquired using a Cartesian, ECG triggered, dual-venc acquisition with an undersampling factor of 8 (spatial res.: $0.8x0.8x0.8mm^3$, FOV: $120x120x30mm^3$, temporal resolution: 42ms, venc:20 and 150cm/s). Data were reconstructed using k-t PCA[7] and combined using the reconstruction presented in Ref[8]. Due to the lack of static tissue, eddy-current related phase offsets were corrected by repeating the measurement in a static phantom and subtracting its phase from the actual acquisition[1]. Flow data were analysed offline using GTFlow (Gyrotools, Zurich, CH). Particle traces ejected from an emitter plane placed at the base of the aneurysm's neck were tracked throughout the cardiac cycle. Through-plane flow was quantified in three contours placed inside the aneurysm (Fig. 1).

Results: The advantage of using a dual-venc acquisition as compared to a standard single-venc technique is exemplarily demonstrated in Fig. 2. It shows particle traces in the double-stented aneurysm model for a single-venc (left) and a dual-venc (right) reconstruction. Particle traces in the five different models acquired with the dual-venc acquisition are shown in Fig. 3. Note the change in flow direction (grey arrow) in the different models. A plot of the maximum and minimum through-plane velocity within the contours is plotted in Fig. 4.

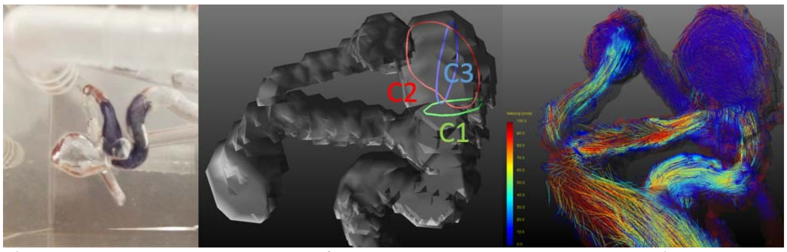

Fig. 1: Photo and rendered volume of an aneurysm model. The three analysis planes are denoted C1, C2, and C3. Particle traces within the entire stented aneurysm model are shown in the right image (velocity range display: 0-100cm/s).

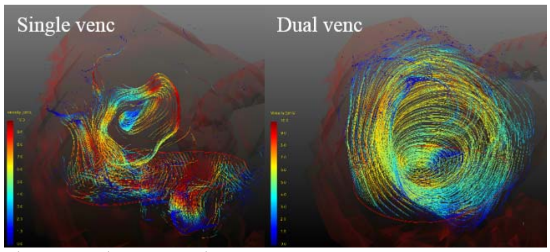

Fig. 2: Particle traces in the double-stented aneurysm model. Single-venc (left) and dual-venc (right) reconstructions are shown at t=350ms (velocity range display: 0-10cm/s).

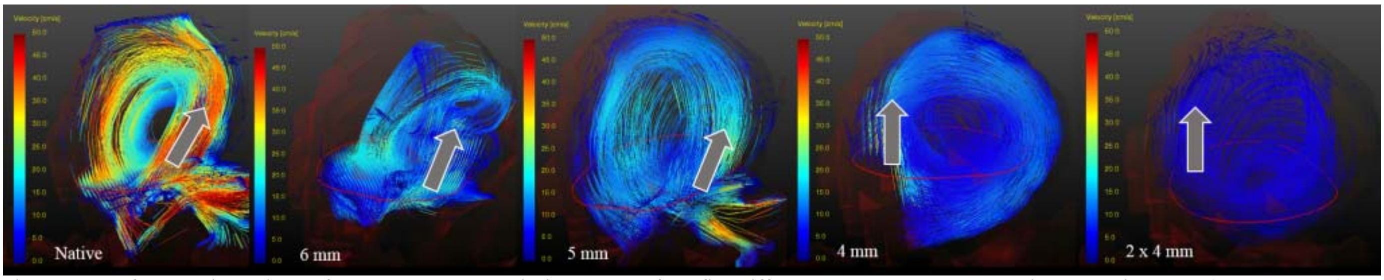

Fig. 3: Traces from particles ejected from a contour placed inside the sac of the five different aneurysm models (velocity range display: 0-50cm/s) at t=350ms. The arrow demonstrates the main velocity direction.

Discussion: The present work demonstrates the feasibility of measuring a wide spectrum of velocities within native and stented aneurysm models. The use of a dual-venc technique is shown to enable accurate flow analysis within the aneurysm even if the maximum velocity is of an order of magnitude smaller than the maximum velocity in the parent artery. The use of k-t PCA allows an 8-fold acceleration as compared to a fully sampled dataset resulting in a net acceleration factor of 7 (taking into account the acquisition of the training data). Results demonstrate drastically differing flow behaviors in the aneurysm models, depending on the choice of the flow diverting stent. In the present models, a minimal flow entering the aneurysm is seen when using a doubled 4 mm device. Although MRI signal loss is observed, flow can still be depicted inside the device (Fig. 1).

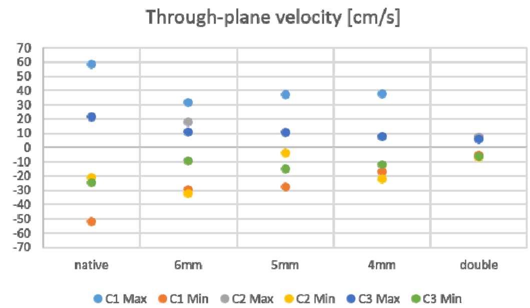

Fig. 4: Maximum and minimum through-plane velocities in the three contours for the five aneurysm models.

Conclusion: Initial results demonstrate the significance of stent sizing on hemodynamic parameters and therewith the difficulty of predicting postinterventional flow conditions. The building of an aneurysm model in combination with the presented acquisition technique gives valuable insights into these conditions. Ongoing analysis of the data includes the quantification of wall shear stress and vortices within the aneurysm dome[9], and the mapping of turbulent kinetic energy[10-11]. An extension to different aneurysm geometries as well as aneurysm types (fusiform) is warranted. Future work will further include the application of the technique in an in-vivo setting prior to and following stent implantation.

References: [1]Chen et al. Neurosurgical Focus 2004, [2]Rahman et al. Stroke 2010, [3]Appanaboyina et al. IntJNumerMethodsFluids 2008, [4]Schnell et al. ISMRM 2013, [5]Acevedo-Bolton et al. JCMR 2013, [6]Markl et al. JCMR 2011, [7]Pedersen et al. MRM 2009, [8]Lee et al. MRM 1995, [8]Chernobelsky et al. JCMR 2007, [9]Stalder et al. MRM 2008, [10]Dyverfeldt et al. MRM 2006, [11]Binter et al. MRM 2012