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A study of flow dynamics in a realistic aneurysm phantom using MPI, MRI and OT

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Abstract

The flow dynamics in a realistic aneurysm phantom were investigated using real-time 3D Magnetic Particle Imaging (MPI). As reference, the flow dynamics were determined using Optical Transmission (OT) and 4D flow Magnetic Resonance Imaging (MRI). The measured flow dynamics with MPI, OT and MRI are in good agreement.

I. Introduction

Rupture and treatment complications of aneurysms, a pathological enlargement of a blood vessel, can lead to life-threatening bleeding [1,2]. Flow dynamics may play an important role in understanding aneurysm formation and rupture. In this study, Magnetic Particle Imaging (MPI) [3], Optical Transmission (OT) [4] and 4D flow Magnetic Resonance Imaging (MRI) [5] were used to investigate the flow dynamics in a realistic aneurysm phantom. MPI enables direct imaging of a tracer bolus in real-time. OT measures the flow dynamics directly using a coloured bolus but requires a translucent sample. 4D flow MRI as a reference enables to measure 3D flow fields and the determination of multiple parameters, such as wall shear stress, with good precision but with the disadvantage of long acquisition times. The aim of this study is to investigate the flow dynamics in a realistic aneurysm phantom with MPI, OT and 4D flow MRI.

II. Methods and materials

Phantom

The aneurysm phantoms used were manufactured following a step-by-step description [6,7] (see Fig. 1).

Magnetic Particle Imaging (MPI)

A bolus of 200 µl Perimag® (Micromod, Germany) was directly visualized using a 3D sequence [8] in an MPI scanner based on the Traveling Wave Principle (TWMPI) using an FFL encoding scheme [8]. The TWMPI scanner provides a fast coverage of the entire FOV within 20 ms scan time and a spatial resolution of 2-3 mm [9].

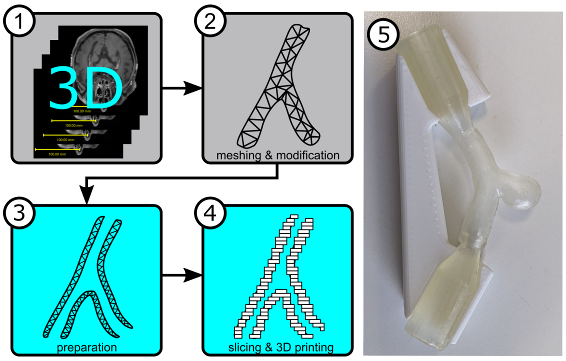

Figure 1: Manufacturing process for vessel phantoms: **(1)** 3D data acquisition of the desired anatomical region with MRI or CT. The extracted 3D model **(2)** can be modified and is prepared for 3D printing **(3)**. The resulting 3D model is printed using an SLA printer (Form3, Formlabs, USA) with flexible resin (Elastic50A, Formlabs, USA) **(4)**. The final aneurysm phantom in a mount for correct anatomic geometry and positioning is shown in **(5)**.

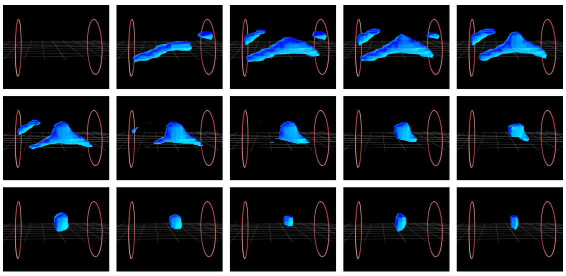

Figure 2: Time series of bolus Perimag® flowing through aneurysm phantom measured with MPI. The red circles indicate the limits of the field of view (FOV).

Optical Transmission (OT)

A 2 ml food color bolus under pulsatile flow (pump: Ismatec MCP-Z, Cole-Parmer GmbH, Germany; 1,251 ml/min; 0.6 s no flow, 0.2 s flow) was filmed with a CCD camera in slow motion (100 fps).

4D flow Magnetic Resonance Imaging (MRI)

A kt-GRAPPA (R=5) accelerated cartesian sequence [9], which combines 3D spatial encoding with 3D velocity encoding, was used to measure pulsatile flow with femoral waveform (pump: Compuflow 1000 MR, Shelley Medical Imaging Technologies, Canada) with 25 ml/s peak flow in 3T Magnetom Vida (Siemens Healthineers, Germany).

III. Results

The flow dynamics in a realistic aneurysm phantom were measured and visualized with MPI (see Fig. 2).

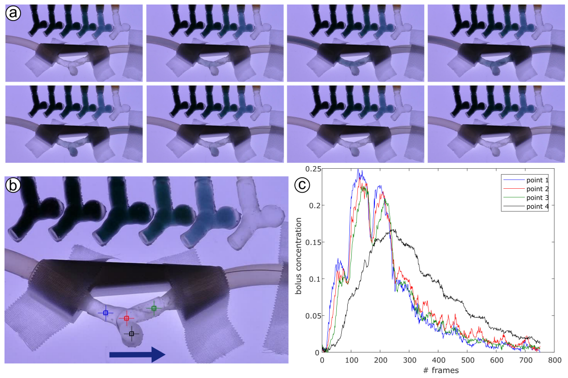

Figure 3: **(a)** Time series of food color bolus flowing through aneurysm phantom under pulsatile flow (1251 ml/min, 0.2/0.6s w/wo flow) filmed in slow motion mode (100fps). **(c)** Intensity over time at four different positions as indicated in **(b)**.

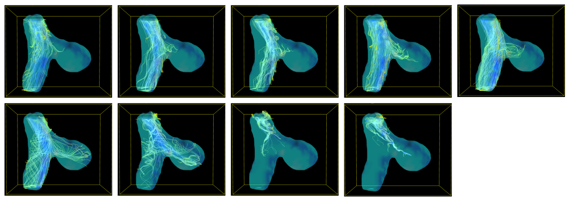

Figure 4: Streamline visualization of flow dynamics in an aneurysm phantom measured with 4D flow MRI at 25 ml/min peak flow.

For comparison, OT and 4D flow MRI measurements were performed. The time series determined with OT are displayed in Fig. 3 and the streamline visualization of a time series measured with 4D flow MRI is shown in Fig. 4.

IV. Conclusion and discussion

To conclude, the flow dynamics in a realistic aneurysm phantom could be measured and visualized with MPI, OT and 4D flow MRI and show good agreement providing complimentary information on flow field and tracer distribution. The fluid initially passes the aneurysm, partially swirls into the aneurysm, and remains there for an extended period. Further studies are needed to investigate the influence of several parameters on flow dynamics such as vessel curvature.

Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study.

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