International Journal on Magnetic Particle Imaging
Vol 8, No 1, Suppl 1, Article ID 2203035, 3 Pages

Infinite Science Publishing

Proceedings Article

Highly Flexible Human Aneurysm Models for Realistic Flow Experiments with MPI and MRI

T. Reichl[a,*] · P. Winter[a,d] · K. Andelovic[d,e] · W. R. Bauer[d] · P. M. Jakob[a] · T. A. Bley[b] · V. Herold[a] · V. C. Behr[a] · S. Herz[b] · P. Vogel[a]

[a] Department of Experimental Physics 5 (Biophysics), University of Würzburg, Germany
[b] Department of Diagnostic and Interventional Radiology, University Hospital Würzburg, Germany
[c] Department of Diagnostic and Interventional Neuroradiology, University Hospital Würzburg, Germany
[d] Medical Clinic and Policlinic I, University Hospital Würzburg, Würzburg, Germany
[e] Institute for Experimental Biomedicine, University Hospital Würzburg, Würzburg, Germany
*Corresponding author, email: Teresa.Reichl@stud-mail.uni-wuerzburg.de

Abstract

4D flow experiments, as known from MRI, are useful to examine the fluid dynamics in complex vessel geometries with high accuracy. The transfer to a positive contrasted fast and sensitive modality, such as MPI, offers new insights into dynamic particle flow under real-time visualization. In particular, measurements in 3D printed vascular phantoms are beneficial since they allow studies of the complicated flow-related interrelations causing the development of pathologies and also provide a quality control for the development of more realistic vascular phantoms. The presented framework provides an easy-to-use processing from extraction of desired vessel structures from 3D MRI or CT data over preparation them for 3D printing and further processing to final measurements.

I. Introduction

Magnetic Particle Imaging (MPI) is a positively contrasted, highly sensitive and fast imaging technology for realtime tomographic visualization up to 2000 frames per second in 2D or 46 volumes per second in 3D [1-5].

These features allow the investigation of hemodynamics of complex vessel geometries such as aortic arch or aneurysms. Flow measurements using 4D phase contrast (PC) magnetic resonance imaging (MRI) are a versatile and established tool to examine accurate information about wall shear stress (WSS) and flow directions with high accuracy [6]. A combination of both modalities, MPI and MRI, can help to understand more deeply the complexity of these parameters and offers a better insight into flow dynamics under realtime conditions as provided by MPI. However, the use of realistic vessel phantoms in combination with pulsatile flow has great potential to study the complicated fluid dynamics and the mechanisms leading to pathological changes under controlled conditions [7, 8].

In this abstract, a framework is presented to extract desired vessel structures from given 3D CT or MRI data set and prepare them for further 3D printing process to create realistic phantoms for pulsatile flow experiments within imaging modalities such as MRI or MPI.

II. Material and methods

II.I. Vessel phantom

The fabrication of the vascular phantoms was performed in several steps as indicated in Fig. 1 [9]. After data acquisition (Fig.1.I), the desired vessel structure is extracted

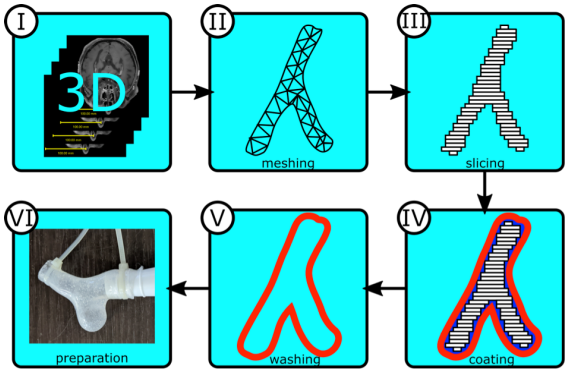

Figure 1: From 3D data to flow phantom: the 3D data (I) are used for extraction of desired vessel region (II – meshing). The STL file is printed with a water-solvable filament (PVA) (III – slicing) and coated with xylitol and silicone (IV – coating). After washing out the PVA and xylitol (V – washing), the phantom can be prepared for experiment (VI – preparation).

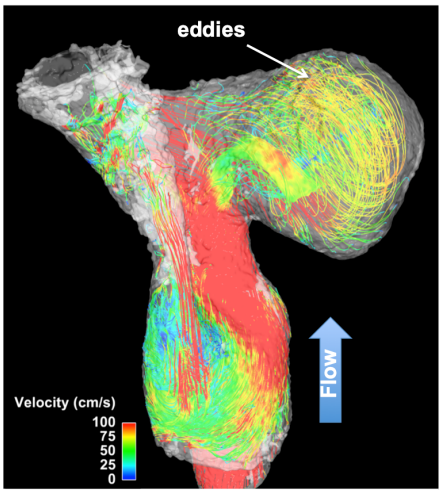

Figure 2: Streamline visualization of the flow through the aneurysm phantom (constant flow mode: 1500ml/min).

from a high-resolution isotropic 3D CT/MRI dataset using a dedicated framework for vessel wall extraction (Fig.1.II) [10]. The converted STL file of the desired vessel was printed as a solid model using polyvinyl alcohol (PVA) filament (Fig.1.III) printed with a desktop 3D printer (N2, Raise, USA). In a next step, the phantom was coated with small layer of xylitol and finally casted with two layers of silicone (∼2 mm thickness, shore hardness A32) (Fig.1.IV). The vascular phantom was immersed in water after silicone coating and became completely hardened. The PVA model and xylitol coating should melt into water (Fig.1.V). Finally, the phantom was prepared for experiments (Fig.1.VI).

II.II. MRI measurements

The MRI experiments are conducted on a 7T small animal MRI system with a custom self-gated radial 4D phase contrast cine MRI sequence using a balanced 4-point flow-encoding scheme (scan parameters: TR/TE: 10.0/1.8 ms, flip angle 20°, 5.9x10^3 radial projections, encoding velocity: 125 cm/s). The total scan time is 39 minutes. For the constant flow setting, the flow is set to 1500ml/min. $CuSo_4$-doped water (concentration: 0.5%) is used as medium.

II.III. MPI measurements

Initial MPI measurements have been performed within a Traveling Wave MPI (TWMPI) scanner using a 3D slicing sequence with 32 projections [11, 12]. The phantom has been filled with a 1:10 dilution of Perimag (Micromod, Germany) with an iron concentration of 25 mg/ml.

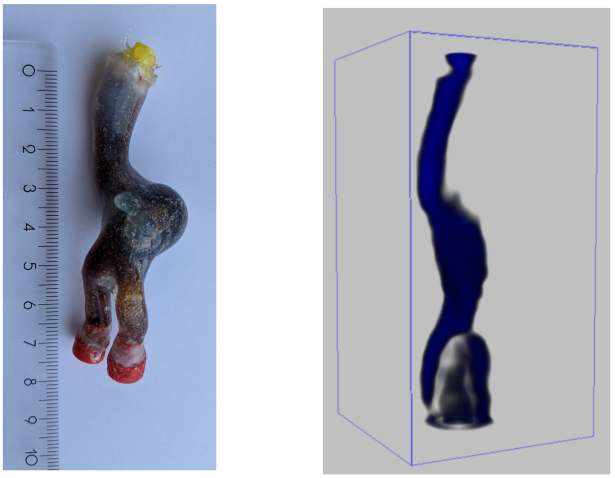

Figure 3: Left: realistic aneurysm phantom filled with diluted Perimag. Right: 3D visualization of TWMPI experiment.

III. Results and discussion

III.I. Flow Measurements

Flow was measured in vascular phantoms using the constant flow mode of the flow pump. Fig.3 displays a streamline representation of the flow through the vessel, indicating the direction and magnitude of the velocities. Near the bottleneck of the phantom an increase of the flow values is observable. In the bulge, large eddy currents are prominent.

III.II. MPI Measurements

The results of the static MPI experiments can be seen in Fig. 3 with the filled realistic phantom on the left side and the 3D visualization on the right.

10.18416/ijmpi.2022.2203035

IV. Conclusions

This abstract demonstrates a framework for the generation of realistic phantoms from real 3D CT or MRI data. In initial MRI and MPI experiments, the usability of a 3D printed aneurysm phantom has been shown under realistic flow conditions. This technique can be used to study the complex fluid dynamics under controlled environments. It has great potential for preclinical studies of the formation mechanics of arterial aneurysms and can be used to study the influence of parameters such as geometry and elasticity on the WSS distribution. Furthermore this *in vitro* platform provides a potential tool to optimize the flow-encoding sequence for subsequent *in vivo* measurements and for a quality control for the development of more realistic vascular phantoms.

Acknowledgments

This work was partially funded by the Deutsche Forschungsgemeinschaft (SFB1158 A10, ZE827/15-1, BA 1069/14-1, HA 7152/8-1, HE 7108/3-1, VO 2288/1-1, VO2288/3-1), the Bundesministerium für Bildung und Forschung (BMBF01, E01004), the University of Wuerzburg in the funding program Open Access Publishing and the Comprehensive Heart Failure Center (Deutsches Zentrum für Herzinsuffizienz).

Author's statement

Conflict of interest: Authors state no conflict of interest.

References

[1] B. Gleich & J. Weizenecker, Tomographic imaging using the nonlinear response of magnetic particles, Nature, vol. 435, pp. 1214–1217, 2005.

[2] M. Graeser et al., Towards Picogram Detection of Superparamagnetic Iron-Oxide Particles Using a Gradiometric Receive Coil, Sci Rep, vol. 7:6872, 2017.

[3] P. Vogel, et al., Superspeed Traveling Wave Magnetic Particle Imaging, IEEE Trans Magn, vol. 51(2):6501603, 2015.

[4] P. Vogel et al., Superspeed Bolus Visualization for Vascular Magnetic Particle Imaging, IEEE TMI, vol. 39(6), pp. 2133-9, 2020.

[5] J. Weizenecker et al., Three-dimensional real-time in vivo magnetic particle imaging, PMB, vol. 54, pp. L1-L10, 2009.

[6] P. Winter, K. Andelovic et al., Fast self-navigated wall shear stress measurements in the murine aortic arch using radial 4D phase contrast cardiovascular magnetic resonance imaging at 17.6T, JCMR, vol. 21:64, 2019

[7] M.G. Kaul et al., Magnetic particle imaging for in vivo blood flow velocity measurements in mice, PMB, vol. 63:064001, 2018.

[8] J. Sedlacik et al., Detection of flow dynamic changes in 3D printed aneurysm models after treatment, IJMPI, vol. 3(1):1703005, 2017.

[9] K. Guggenberger et al., Intracranial vessel wall imaging framework – Data acquisition, processing, and visualization, MRI, vol. 83, pp. 114-24, 2021

[10] Y. Liu et al., Fabrication of cerebral aneurysm simulator with a desktop 3D printer, Sci Rep, vol. 7:44301, 2016.

[11] P. Vogel et al., Traveling Wave Magnetic Particle Imaging, IEEE TMI, vol. 33(2), pp. 400-7, 2014.

[12] P. Vogel et al., Real-time 3D Dynamic Rotating Slice-Scanning Mode for Traveling Wave MPI, IJMPI, vol. 3(2):1706001, 2017.

