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Realistic vascular 3D printed phantom for real-time bolus tracking in a human-sized MPI scanner

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Abstract

Phantoms of blood vessels are an important part of flow measurements and should behave as realistic as possible compared to human blood vessels. A step-by-step guide is presented on how to obtain realistic 3D models of blood vessels applicable for 3D printing and simulation studies. The resulting 3D models have realistic dimensions, are waterproof and could be used in a human-sized MPI scanner. The 3D printed phantoms with vascular pathologies like aneurysm or stenosis were used in static and real-time bolus tracking measurements.

I. Introduction

Human-sized Magnetic Particle Imaging (MPI) scanners are the next step on the way to clinical application. First scanner designs have been shown [1] and built [2, 3] demonstrating the feasibility of scaling up the hardware of this young technology [4].

Realistic phantoms are essential for investigating novel approaches and protocols, especially in medicine. For that the phantoms should provide multiple features such as realistic dimensions, surfaces (especially the inner surface), and the behavior to mimic the flexibility and mechanical response of vessels to the human pulsatile blood flow.

In clinical environment, there are several approaches for acquiring appropriate data sets for different cases. Since 3D information available from CT or MRI machines is provided as 3D voxel arrays, the desired structures must be extracted in a prior step and prepared for further processing, e.g., for 3D printing.

In this abstract, a step-by-step guide is presented to extract vascular pathologies from real datasets creating highly resolved 3D surface models, which can be used for 3D printing and further experiments as well as simulation studies.

II. Material and methods

For extraction of desired structures, such as vessels, of provided CT or MRI 3D datasets, a home-built software providing a simple 3D GUI is used [5]. In Fig. 1 (1), the sketch shows the procedure starting with the 3D data acquisition in a CT or MRI machine with desired spatial resolution. A voxel-vise data extraction, e.g., by using 3D Dijkstra algorithm, results in a voxel model, which can be converted into a triangle mesh surface model (format: stl-

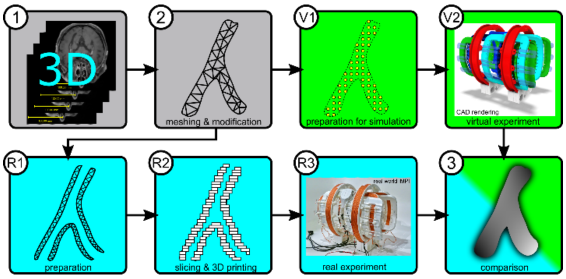

Figure 1: Sketch of the 3D model extraction concept: (1) 3D data are taken within a CT or MRI machine. (2) with an appropriate software, the desired 3D structure can be extracted and converted into a triangle mesh surface model. After modification (inducing different medical conditions – see Fig. 2), the 3D model can either be used within simulation software for investigation of the expected signals (V1) & (V2) or further prepared for 3D printing (R1) & (R2) before measured in a real MPI scanner. Both results can be compared afterwards (3).

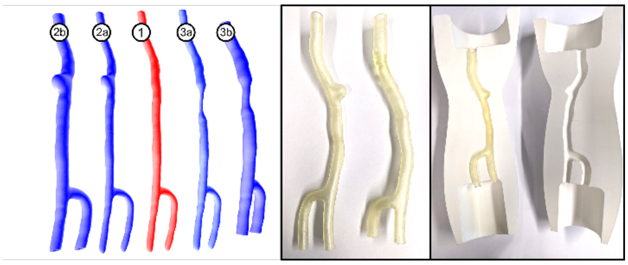

Figure 2: Exemplary modifications of an extracted vessel structure (1) (red). Left: By inducing different medical conditions, e.g., an aneurysm (2a) & (2b) or a stenosis (3a) & (3b), these different cases can be evaluated within a simulation framework or a real MPI scanner. Right: photo of a ready-to-use vessel phantom with aneurysm and stenosis, which can be fitted inside of a 3D printed artificial leg.

file – standard triangle language) using Marching cube algorithm. With this standard data format, the 3D model can be modified (see Fig. 1 (2)) and further processed. As indicated in Fig. 1 (V2), the model can directly be used within a home-build MPI simulation framework [6] for simulation of realistic MPI scanners. In a second way, the 3D model is prepared for 3D printing by hollowing out and slicing. At the end, both results can be compared.

In Fig. 2, the preparation process of an extracted vessel from a human leg is shown. Fig. 2 (1) shows the initial extraction model which corresponds to the inner volume of the extracted vessel. In a first step (Fig. 2 (2a) or (3a)) a medical condition is induced, e.g., an aneurysm or stenosis. Now these models define the inner structure of the final phantoms. In a final step (Fig. 2 (2b) or (3b)), the 3D models are inflated (3D offset) with the desired wall thickness and hollowed out.

In a final step, the extracted models were 3D printed with SLA 3D printer (Form3, Formlabs, USA) using a highly flexible material (Elastic 50A resin, Formlabs, USA). This resin was chosen to simulate the elasticity and flexibility of blood vessels. An additional feature is the water-resistance of the phantoms, which allows the use for real experiments, e.g., flow experiments and bolus tracking [7].

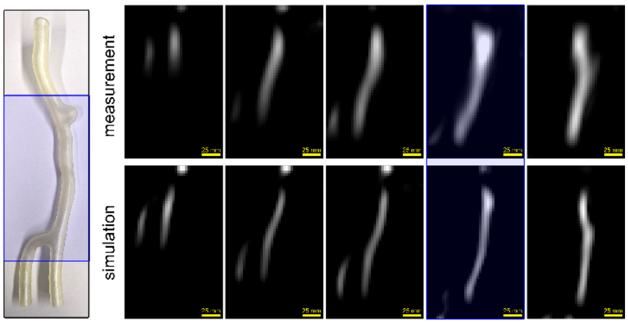

Figure 3: Aneurysm phantom at different positions along the symmetry axis (z-axis) through the real (top) and virtual (bottom) iMPI scanner [3].

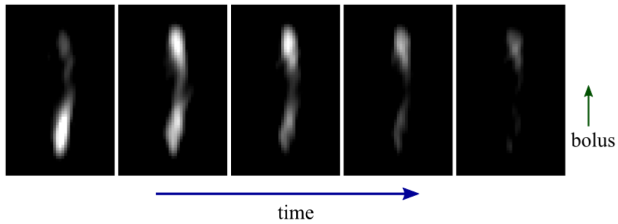

Figure 4: Realtime bolus tracking in a stenosis measured in a human-sized MPI scanner with 4 frames per second. A 1 ml bolus of Perimag® (iron concentration of 25mg/ml) under continuous water flow was visualized. The size of the FOV is 10×25 cm^2.

III. Results and discussion

The application of the 3D printed phantoms was shown in a human-sized MPI scanner [3]. Therefore, an aneurysm phantom was measured static and a stenosis phantom with real-time bolus tracking.

Figure 3 shows the static measurement of the aneurysm phantom (Fig. 2 (2b)). It is moved along the z-axis through the real (top) and virtual (bottom) iMPI scanner to compare both results. A good agreement of both reconstruction series is given.

In Fig. 4, a real-time bolus tracking image sequence is shown. A 1 ml bolus of Perimag® (micromod GmbH, Germany; iron concentration: 25 mg/ml) under continuous water flow was measured with 4 frames per second in a human-sized MPI scanner [3].

IV. Conclusions

This abstract demonstrates a step-by-step guide to extract vascular structures and pathologies from 3D CT or MRI datasets and to create 3D surface models. By printing the 3D models using a highly flexible resin, waterproof vessel phantoms with realistic dimensions can be obtained. Moreover, these phantoms can be used for static and real-time bolus tracking measurements in a human-sized MPI scanner. With this framework, an easy-to-use technique is available for generating large and realistic phantoms for (human-sized) MPI scanners.

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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.

References

[1] E. E. Mason, et al., *Design analysis of an MPI human functional brain scanner*, Int. J. Magn. Part. Imaging, vol. 3(1):1703008, 2017

[2] M. Graeser et al., *Human-sized magnetic particle imaging for brain applications*, Nature Comm, vol. 10:1936, 2019.

[3] P. Vogel et al., *iMPI – portable human-sized Magnetic Particle Imaging Scanner for real-time endovascular Interventions*, PREPRINT (Version 1) available at Research Square doi:10.21203/rs.3.rs-2294644/v1, 2022.

[4] B. Gleich, & J. Weizenecker, *Tomographic imaging using the nonlinear response of magnetic particles*, Nature, vol. 435(7046), pp. 1217–1217, 2005

[5] K. Guggenberger & A.J. Krafft et al., *Intracranial Vessel Wall Imaging Framework – Data Acquisition, Processing, and Visualization*, MRI, vol. 83, pp. 114-24, 2021.

[6] P. Vogel et al., *Highly Flexible and Modular Simulation Framework for Magnetic Particle Imaging*, arXiv:2208.13835, 2022.

[7] T. Reichl et al., *Highly Flexible Human Aneurysm Models for Realistic Flow Experiments with MPI and MRI*, Int J Mag Part Imag, vol. 8(1): 2203035, 2022.

