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3D printed measurement phantoms for evaluation of magnetic particle imaging scanner

S. Dutz[1*], A. Stang[1], L. Wöckel[1], D. Zahn[1], C. Grüttner[2], N. Löwa[3], O. Kosch[3], and F. Wiekhorst[3]

[1] *Institute of Biomedical Engineering and Informatics, Technische Universität Ilmenau, Ilmenau, Germany*
[2] *micromod Partikeltechnologie GmbH, Rostock, Germany*
[3] *Physikalisch-Technische Bundesanstalt Berlin, Berlin, Germany*
[*] *Corresponding author, email: silvio.dutz@tu-ilmenau.de*

Abstract: To assess the potential and capability of different MPI scanner designs and architectures, defined reference phantoms for imaging studies are required. For the preparation of well-defined structures as well as realistic vessel structures, 3D printed molds were filled with magnetic nanoparticles embedded into a long term stable polymeric matrix or perfused with a flowing ferrofluid. Different types and layouts of 3D printed phantoms will be presented which were imaged by means of MPI successfully.

I. Introduction

Magnetic Particle Imaging (MPI) is based on the non-linear dynamic response of magnetic nanoparticles (MNP) to an oscillating magnetic excitation field. In combination with a static gradient field, spatial encoding of an MNP distribution in a volume is given. With detection limits in the nanomolar range [1] of MNP and due to its high spatio-temporal resolution, MPI is suitable for clinical applications like tumor detection or cell labeling [2].

To assess the potential and capability of different MPI scanner designs and architectures, defined reference phantoms for imaging studies are required. Currently, most phantoms for MPI are based on nanoparticle dispersions filled in thin capillaries or containers [3]. The disadvantages of these phantoms are adhesion of the MNP to the walls of the capillaries and particle-particle interactions, often leading to agglomeration processes of MNP. Furthermore, for evaluation of the spatial resolution, such phantoms do not show well-defined dimensions of the particle loaded structures. For preparation of more defined and long-term stable phantoms, in our study 3D printed molds were filled with a MNP loaded polymer matrix.

For investigation of the temporal resolution, dynamic measurement phantoms are needed [4]. Such phantoms enable measurements, in which the velocity of a moving object can be imaged and reconstructed by the scanner. To this end, we present here dynamic phantoms based on segmented flow of a cylindrically shaped bolus (MNP dispersion) within a liquid carrier material in well-defined tube systems as well as more realistic vessel phantoms. For this, molds for holding tubes of different diameters and shapes as well as planar vessel structures were prepared by means of 3D printing.

II. Material and methods

The 3D printed phantoms for evaluation of spatial resolution consist of a mold with eight, radially arranged notches (2 x 2 mm^2 rectangular cross section, 5.4 mm length), see figure 1.

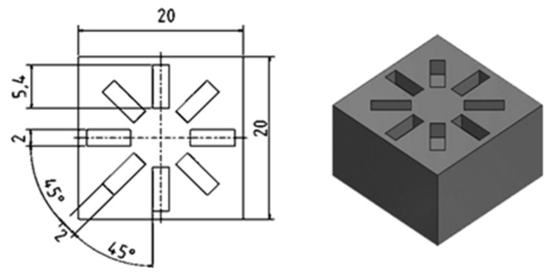

Figure 1: (left) Sketch of the mold, (right) 3D-CAD model.

Molds were printed at Anycubic Photon-5.5 (Shenzhen Anycubic Technology Co. Ltd, Shenzen, China) by using ANYCUBIC 3D Printing UV Sensitive Resin with the following printing parameters: exposure time = 90/60 s, off time = 2 s, and layer thickness = 50 µm.

The notches were filled with approximately 24 µL MNP loaded polymer. For this, commercially available MNP (perimag®, micromod Partikeltechnologie GmbH) were dispersed into long-term stable matrix material (ELASTOSIL®, Wacker Chemie AG) with concentrations up to 200 mmol/L using an ethanol transfer protocol as described before [5].

The phantom setups for evaluation of temporal resolution consist of a tube system of different diameters and the 3D printed vessel phantom filled with a hydrophobic carrier liquid into which a bolus of an aqueous, liquid MNP dispersion (tracer) is added. The MNP system perimag® (micromod Partikeltechnologie GmbH) was chosen as aqueous tracer material for the setup of the dynamic phantoms. As a hydrophobic carrier liquid, silicon oil (Carl Roth, Karlsruhe, Germany) was selected to guarantee the phase separation between tracer bolus and carrier liquid. Due to surface tension and hydrophobicity, the tracer bolus will not mix with the carrier and can accurately be moved through the tube or vessel system by pumping of the hydrophobic carrier. The variation of tube and vessel diameter, carrier flow velocity, and tracer concentration enables the investigation of the temporal resolution of an MPI scanner. For printing of vessel phantom (see figure 2) Photocentric 3D – UV HARD RESIN was used with following printing parameters:

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exposure time = 120/26 s, off time = 2 s, and layer thickness = 50 µm. Printed vessel structures were embedded into ELASTOSIL® to improve its mechanical stability.

Figure 2: Photograph of the 3D printed vessel phantom; edge length = 45 mm.

The phantoms were characterized by imaging with a MPI scanner (MPI 25/20FF, Bruker, Ettlingen, Germany).

III. Results

The MPI reconstructions of phantoms for spatial resolution show the entire geometry of the phantom, see figure 3. Thus, from this materials, long-term stable measurement phantoms for multimodal imaging were prepared, which can be imaged successfully by means of MPI, µCT, and MRI [5].

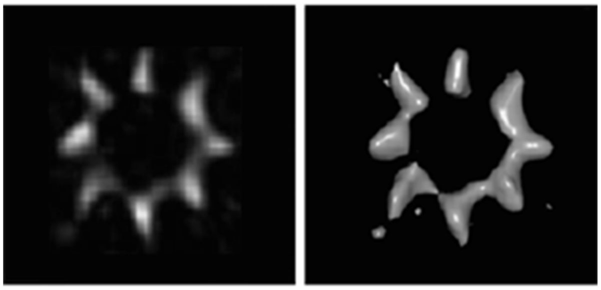

Figure 3: (left) MPI intensity image (right) and surface rendered image of the prepared measurement structures as shown in Fig1.

Moving boluses within tube and vessel structures were imaged by means of MPI successfully. The obtained temporal imaging resolution is defined by the used spatial resolution. For all tube diameters it was possible to reconstruct the moving bolus up to flow velocities of 40 cm/s. Higher flow velocities can't be realized with the present dynamic bolus phantom.

IV. Conclusions

By using 3D printing technologies, we were able to prepare structures for spatial and temporal evaluation of magnetic particle imaging scanners. Especially, for the preparation of realistic vessel structures the 3D printing technology shows a high potential for a low cost and fast production of the phantoms.

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Author's statement

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