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Abstract

Hydrogel-based MPI phantoms

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The validation and performance comparison of imaging modalities, particularly magnetic particle imaging (MPI) [1], requires standardized procedures and phantoms. A challenge for MPI phantoms is the incorporation of structures smaller than 1 mm to demonstrate the high-resolution capabilities, while excluding magnetic or electrically conductive materials. A hydrogel-based phantom is presented, specifically designed for evaluating an in-house developed MPI scanner [2].

Conventional phantom production methods typically involve hollow bodies filled with a magnetic nanoparticle (MNP) solution, leading to structural and procedural complexities that increase costs, prolong lead times, and hinder scalability and reproducibility for various imaging modalities. As an extension, additive manufacturing enables precise geometric realization by printing phantoms as hollow bodies, allowing for flexibility in intricate structures. However, this process requires complex procedures in post-processing, air-free filling and sealing. An alternative option is the direct 3D printing of phantoms by integrating the MNPs into the print material. Integration of MNPs into the resin for resin-based printing processes has proven to be feasible, but presents disadvantages, such as sedimentation and geometric inaccuracies due to incomplete curing [3]. Here, a resolution phantom is presented that has been directly manufactured via semi-solid extrusion, utilizing a suspension of MNPs in a hydrogel. In this initial experiment, a self-sealing phantom holder incorporating a circular print bed with a diameter of 29 mm was developed for integration with the bioprinter and hydrogel used (Bio X6 w. CELLINK START, CELLINK Bioprinting AB, SE). The imageable ink suspension is composed of ~2 ml of hydrogel, which served as a polyethylene oxide-based dispersant offering good mechanical printability, combined with ~110 mg of MNP powder (perimag®, micromod Partikeltechnologie GmbH, DE). The phantom was designed with four lines converging from the center at uniform 24° angular spacing, originating at a radius of 4.1 mm, extending 7.3 mm in length, and maintaining a thickness of 0.4 mm. The print was completed using a 3 ml pneumatic printhead with a 0.2 mm (27G) nozzle at a pressure of 35 kPa, speed of 5 mm/s and temperature of ~37 °C. The phantom retained good shape fidelity and homogeneous material extrusion, was printed in ~90 s and subsequently imaged using the MPI scanner, with slice images obtained by a custom hybrid reconstruction method closely resembling the phantom and demonstrating high imaging quality.

The presented work provides a robust foundation for future studies and considerations aimed at advancing the production of MPI phantoms by leveraging the unique capabilities of additive manufacturing. High-resolution phantoms created with tuneable materials can efficiently address the rigorous requirements of various imaging.

AUTHOR'S STATEMENT
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