Next-Generation Single-Sided MPI Scanner – Towards Clinical Applications

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Introduction: Magnetic Particle Imaging (MPI) is a tracer-based imaging modality that enables high-contrast, radiation-free imaging of superparamagnetic iron oxide nanoparticles (SPIO) [1]. Traditional MPI scanner designs, particularly closed-bore topologies, limit access and subject size, restricting clinical applications. Single-sided MPI scanners [2] eliminate these constraints by enabling open-access imaging that is not restricted by subject dimensions, making them ideal for clinical translation [3]. In this work, we present the next generation of a field-free line (FFL) single-sided MPI scanner [4]. The upgrades highlight the potential of the scanner to significantly improve sensitivity, field of view, and image quality, making it a viable candidate for clinical diagnostics.

Methods: The MPI scanner (Fig.1a) is composed of five electromagnetic coils, three of which are "racetrack" shaped selection coils responsible for generating the FFL and defining its trajectory for spatial encoding. The top coils contain a receive gradiometer and a replaceable organ-specific excitation coil. We utilized various phantoms with SPIO tracer to test imaging and characterize the performance of our scanner. To evaluate the field of view (FOV), we imaged a spiral phantom in the coronal plane. The scan used an 8 cm FOV, a 0.4 T/m gradient, and a 1 mm FFL scan step. Spatial resolution was assessed using a two-rod phantom (25 mm long with a 1 mm diameter, separated by 4 mm) filled with Synomag-D 70 nm (Micromod) SPIO. Imaging sensitivity was evaluated using 18 µL glass bulbs filled with diluted concentrations (1:1 to 1:64) of Synomag-D 70 nm.

Results and discussion: The presented results of imaging a 3D-printed spiral phantom filled with Synomag-D SPIO demonstrate a unique large FOV of 8 cm in a twofold increase of FOV over the previous system, which exceeded the FOV of the existing commercial preclinical scanners. The spatial resolution scan produced a 2D image in which the 4 mm spaced rods were distinguishable without digital alteration of image reconstruction. In the dilution imaging experiment, the lowest imaged sample corresponded to ~2.0 µg of iron content. This result meets the small tumor detection threshold of 4.8 µg of iron for a 1 mm^3 tumor size based on a 400 mg iron dose.

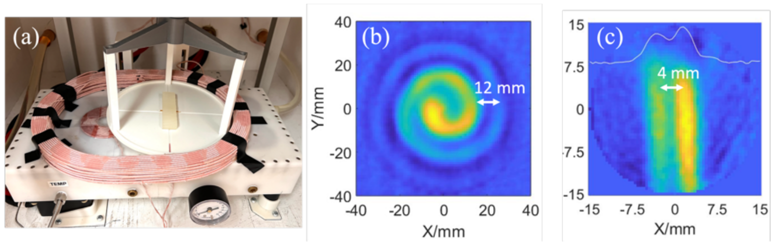

Fig. 1: a) Single-sided FFL MPI scanner with a resolution phantom; b) coronal image of spiral phantom; c) coronal image of two-rods resolution phantom.

Conclusion: We demonstrate significant improvements to a single-sided MPI scanner: enhanced spatial resolution, increased imaging sensitivity, and an expanded linear FOV. Moreover, the achieved spatial resolution falls within the range of human head MPI systems, which typically operate with gradients between 0.2–1.1 T/m, yielding corresponding resolutions of 12 mm to 3 mm [5-7]. Our scanner achieves this range with notably lower hardware complexity and power requirements. The imaging sensitivity meets the threshold for SPIO-labeled tumor detection. These results support the viability of the system for future clinical applications.

References: [1] Gleich, B., Weizenecker, J. Nature 435, 1214-1217 (2005). [2] Sattel, T. F et al. J. of Phys D : Appl Phys, 42, p.022001 (2009). [3] Kaethner, C. et al. IEEE Trans Magn 51, 2, 1–4 (2015). [4] McDonough, C., Chrisekos, J., and Tonyushkin, A. IEEE Trans Biomed Eng 71, 3470–3481 (2024). [5] Thieben, F. et al. Commun Eng 3, 47 (2024). [6] Sehl, O. C. et al. Mol Imag and Biol 27, 78–88 (2025). [7] Mattingly, E. et al. Phys Med Biol 70, 015019 (2025).