Magnetic Particle Imaging for Safe Angiography and Stem Cell Tracking

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Introduction: Magnetic Particle Imaging (MPI) is a new imaging modality that re-uses FDA-approved superparamagnetic iron oxide (SPIO) nanoparticle contrast agents in a new imaging scanner (i.e., not an MRI scanner) [1-3]. The MPI method has ideal SNR, penetration, linearity and contrast, and is completely non-invasive. Moreover, compared to iodine and gadolinium, the SPIO contrast agents are much safer for patients with Chronic Kidney Disease (CKD). This work describes our state-of-the-art MPI scanners and MPI's potential for applications such as angiography and quantitative cell tracking.

Methods and Results: Fig. 1 shows two different geometries of MPI scanners built in our lab: (1) The FFP scanner (Fig. 1a) is constructed using opposed NdFeB permanent magnets that produce a Field Free Point (FFP) at the magnet iso-center. Images from this system have ~2 millimeter resolution using Resovist SPIO tracer (Fig. 1b). (2) The projection (FFL) scanner (Fig. 1c) is constructed using two rectangular NdFeB permanent magnets that produce a Field Free Line (FFL) along the up/down direction. The FFL produces projection MPI images (Fig. 1d). The resolution in MPI scales with the magnetic field gradient. Hence, the FFP scanner has approximately 3 times finer resolution than the projection (FFL) scanner.

With our FFL scanner, we can rotate the sample and acquire projection images at multiple angles. These images can then be reconstructed via filtered backprojection (similar to CT) to form a three-dimensional MPI image with 10-fold improvement in SNR. Fig. 2 shows one such volume-rendered MPI image of a vasculature-mimicking phantom acquired with 40 projections.

In Fig. 3, human embryonic stem cell (hESC)-derived cells were labeled with Resovist SPIOs [4], injected subdermally into a postmortem mouse, and imaged on the FFL scanner. The signal intensity scales linearly with the number of cells. There is no background signal from the mouse tissue, showing MPI's high contrast and sensitivity for cell tracking applications.

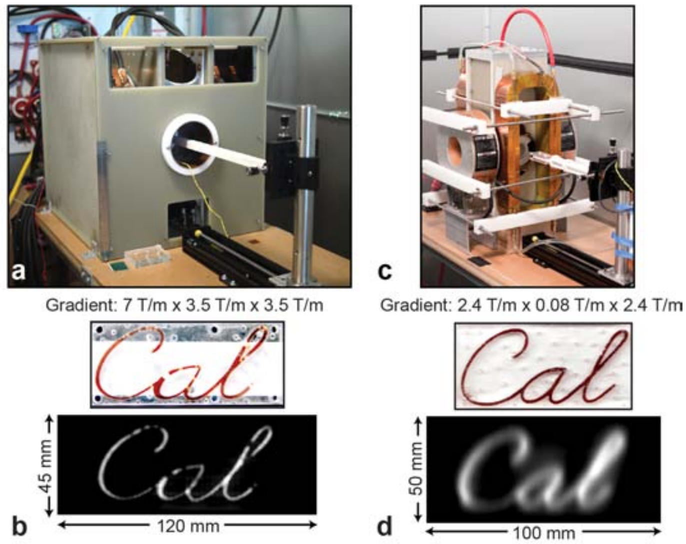

Figure 1: *MPI scanners built in our lab already demonstrate millimeter-scale resolutions.* ***(a)*** *FFP and* ***(c)*** *Projection (FFL) MPI scanners. MPI images of "Cal" phantoms filled with 10x diluted Resovist SPIOs acquired with* ***(b)*** *FFP and* ***(d)*** *projection MPI scanners. Due to stronger magnetic field gradients, the image in (b) has 3x finer resolution than the image in (d).*

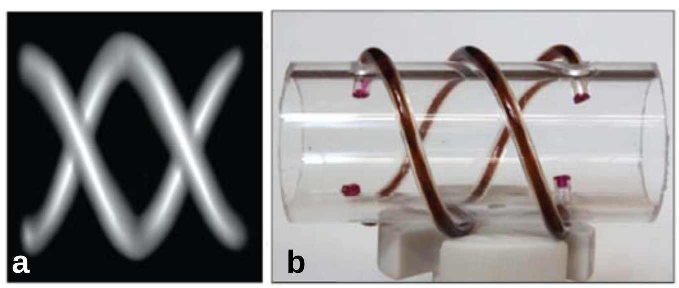

Figure 2: *MPI image of a vasculature-mimicking helical phantom filled with undiluted Micromod nanomag-D SPIOs, acquired on our projection (FFL) MPI scanner.* ***(a)*** *Volume-rendered MPI image after 3D projection reconstruction of 40 projections.* ***(b)*** *Photo of the phantom (tubing ID: 1.6 mm). 2 min 7 s scan. FOV: 6 x 6 x 7.3 cm^3.*

Discussion: We have demonstrated MPI's potential for angiographic and cell tracking applications. MPI exhibits near perfect contrast with no background signal, as well as quantitative imaging capabilities. With hardware improvements and optimized SPIOs, we believe that MPI can soon achieve resolutions comparable to those seen in MRI.

References: 1. Gleich B., Weizenecker J. Nature 2005;(435):1214-17. **2.** Goodwill PW, Conolly SM. IEEE TMI. 2010;29(11):1851–9. **3.** Goodwill PW, et al. IEEE TMI. 2012;(c):11–13. **4.** Arbab AS, et al. Blood. 2004;104(4):1217–23.

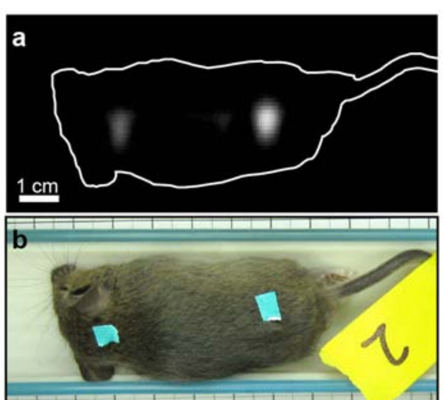

Figure 3: *Stem cell tracking with MPI.* ***(a)*** *Projection MPI image of hESC-derived cells (100K cells on the left vs. 200K cells on the right) introduced subdermally into a postmortem mouse (injection sites marked in cyan in* ***(b)****). The ratio of signal intensities between the right and left injection regions in the MPI image was 2.1, demonstrating quantitative imaging capability of MPI. 4 minute scan, FOV: 5 x 10 cm^2.*