Direct Imaging of Ferumoxides using Magnetic Particle Imaging: Sensitivity, and Instrument Construction

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Intro: Magnetic Particle Imaging (MPI) is a new imaging modality [1] that promises long-term detection and tracking of nano-mol/L concentrations of super-paramagnetic iron oxide (SPIO) commonly used as MRI contrast agents. MPI can detect SPIOs attached to cells or injected into the blood stream without the depth limitations of optical imaging and without radiation. The MPI method directly detects the magnetization from an SPIO whose saturation magnetization approaches 0.6T, or 10^6 times larger than the nuclear paramagnetism detected by MRI at 7 Tesla. The estimated 20nmol/L detection limit [1], corresponding to a 200x SNR boost over MRI at detecting SPIOs, still needs to be experimentally verified.

Methods: We measured the sensitivity of a small bore (3.8cm free bore, 1.5cm usable bore) prototype MPI system. The prototype we have developed uses narrowband MPI, allowing small receive bandwidths at high frequencies with a clear path towards body noise dominance [2]. The system uses a permanent NdFeB magnet gradient (dB/dz=4500mT/m, dB/dx,y=2600mT/m) and fits a 1x1x10cm sample.

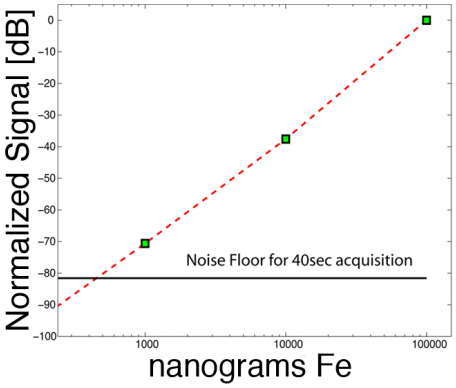

Figure 1: Signal magnitude and noise floor measurement of narrowband MPI prototype showing 400ng detection limit.

Results: Figure 1 shows the sensitivity of our MPI system in directly detecting the magnetization of SPIO nanoparticles. We measure a 400ng Fe detection limit (50nm SPIO particles, Figure 1), with significant room for SNR improvement (>10x) as we increase excitation fields, improve electronics, and develop pulse sequences. Figure 2a shows the MPI imager. Figure 2b shows quantitative 3D images of a mouse liver with a measured FWHM of 1.875x1.875x1.25mm. Figure 2c shows a complex "CAL" phantom showing three of 8 acquired harmonics.

Conclusion: We successfully built a MPI system that directly detects the magnetization of iron MRI contrast agents with remarkable sensitivity and resolution. Significant gains in SNR and resolution are possible as we continue to develop pulse sequences, reduce vibration, improve electronics, and develop new hardware. With the significant SNR improvement over MRI, we see great potential for MPI to directly detect SPIOs enabling rapid angiography, inflammation tracking and stem cell tracking.

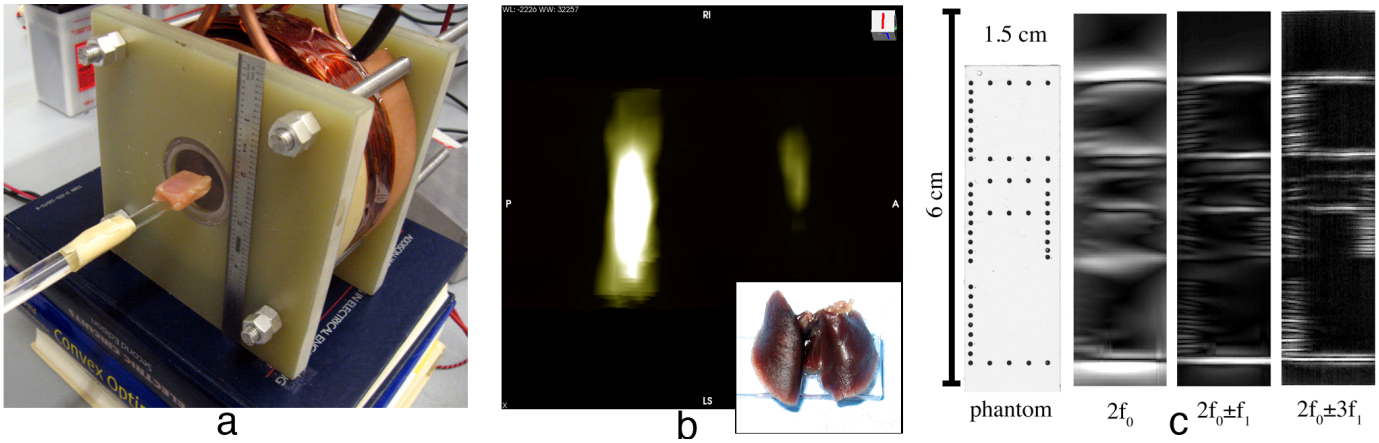

Figure 2: (a) MPI imager with 1x1x2cm tissue sample and 15.24cm (6inch) ruler for reference, (b) Full 3D image of preserved mouse liver injected with 50micro-grams and 25micro-grams 50nm SPIOs. FOV: 1.2cm x 1.2cm x 2cm, 4.3 minute acquisition time. (c) Complex "CAL" phantom showing ability of MPI to resolve a complex phantom. Each point in the phantom contains 25µg Fe. FOV: 1.5cm x 6cm, 10.3 minute acquisition time.

References: 1. B Gleich et al. Nature 435,1214-1217(2005); 2. A Macovski. *Mag Res Med*, 36(3)494-7(1996); 3. P. Goodwill, Proc. WMIC, Nice, Fr, 2008.