Direct Imaging of SPIOs in Mice using Magnetic Particle Imaging: Instrument Construction and 3D Imaging

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Intro: Magnetic Particle Imaging (MPI) is a new imaging modality that promises long-term detection and tracking of nano-mol/L concentrations of super-paramagnetic iron oxide (SPIO) particles commonly used as MRI contrast agents. The MPI method does not use an MRI scanner, instead it 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 have developed the first MPI scanner capable of imaging a whole mouse. The system directly detects the magnetization of iron with remarkable sensitivity and resolution over a 3cm field of view, sufficient for a whole mouse. Our narrowband MPI system is a variant of MPI [1] that enables small receive bandwidths at high frequencies using intermodulation, with a clear path towards body noise dominance [2].

Results: Figure 1a shows a mouse injected with 100µg SPIO tracer. Shown as an overlay over an *in vitro* mouse photo is the MPI image of the SPIO tracer, which is quantitative and high resolution (FWHM ~1mm). The imaged volume is fully 3D, but is shown here as a maximum intensity projection. Figure 1b is the MPI imager built for these studies.

Discussion: The system is capable of full 3D imaging without moving the sample. To achieve this, water cooled electromagnets move the field free point up to ±1.5cm in any direction. The electromagnets are powered using standard MRI gradient amplifiers (Copley Controls 234), requiring up to 450A pulses to image the entire FOV. Simultaneously applied continuous RF power of 10mT at 240kHz elicits a strong signal from the 50nm SPIO particles (FluidMAG-DX, Chemicell GMBH), and is well below the SAR limit for a mouse. The system has a permanent NdFeB magnet gradient (dB/dz=6500mT/m, dB/dx,y=4500mT/m), and is controlled by a MRI console capable of working at low frequencies [3].

Conclusion: We successfully built a MPI system that directly detects the magnetization of iron 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 in rapid angiography, inflammation tracking and stem cell tracking.

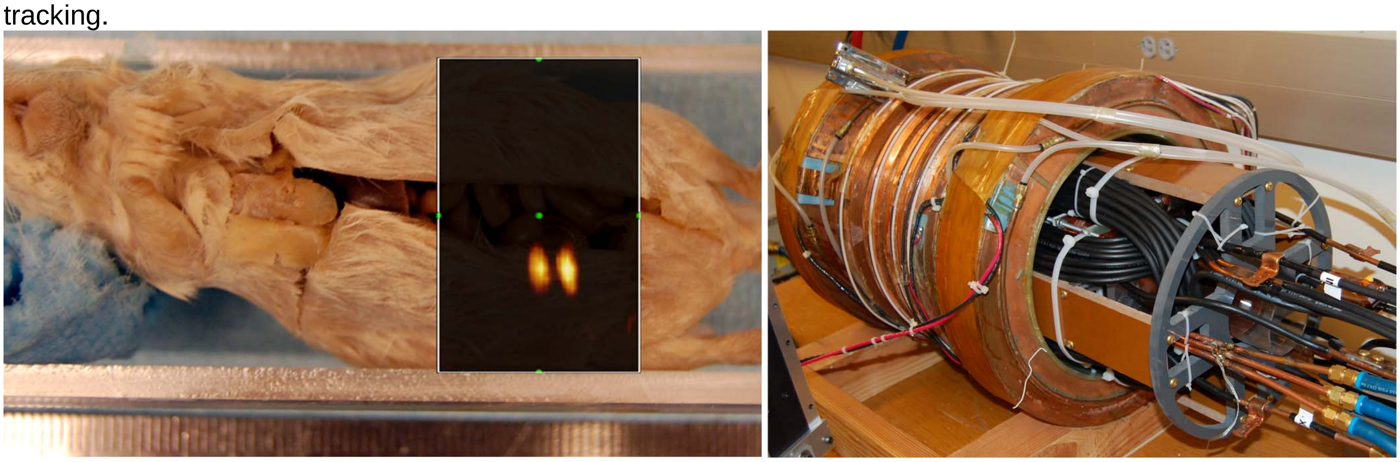

Figure 1: (a) Full sized preserved mouse in sample holder superimposed with Maximum Intensity Projection of full-3D volumetric image of 100µg SPIO tracer injected into large intestine. FOV = 3cm x 3cm x 2cm, N=32x128x40, 7 minute acquisition time. (b) MPI imager partially removed from Z FFP movement magnet. Visible are electromagnets and water cooling tubes.

References: 1. B Gleich et al. Nature 435,1214-1217(2005); 2. A Macovski. *Mag Res Med*, 36(3)494-7(1996); 3. P. Stang et al. Proc. 16^{th} ISMRM, p925, 2007. 4. P. Goodwill, Proc. WMIC, Nice, Fr, 2008.