Magnetic Particle Imaging (MPI) Nanoparticles and Emerging Applications

MPI Technology

MPI is an emerging imaging modality with potential in a number of biomedical applications. This approach detects superparamagnetic iron oxide (SPIOs) nanoparticles, which produce high resolution positive contrast with linearly quantitative signal. As with many other imaging approaches, the image quality and unique capabilities of MPI are dependent on the properties of the SPIO that is used.

Key Properties of Effective MPI Tracers

MPI detects SPIO tracers, which are known to be biocompatible and biodegrade in vivo, making SPIOs an ideal nanomaterial for potential clinical translation [1,2]. Additionally, these particles have several FDA and EU approved formulations [3].

The ideal MPI SPIOs have an ~25 nm core, are monodisperse, stable in solution and easily dispersed in water with amphiphilic polymers (Figure 1a). Furthermore, it is important to ensure the surface coatings promote cellular uptake while preserving optimized magnetic response of SPIOs dispersed in the acidic endosomal environment. It is well known that charge mediates cellular uptake of nanoparticles [5]. For example, SPIOs such as Ferucarbotran (VivoTrax™, Magnetic Insight, Inc.) are more readily taken up by stem cells after incubation with protamine sulfate, a positively charged transfection agent [6]. Additionally, coatings such as polyethylene glycol (PEG) prevent aggregation due to magnetic interactions, minimize non-specific cell uptake and enhance circulation time.

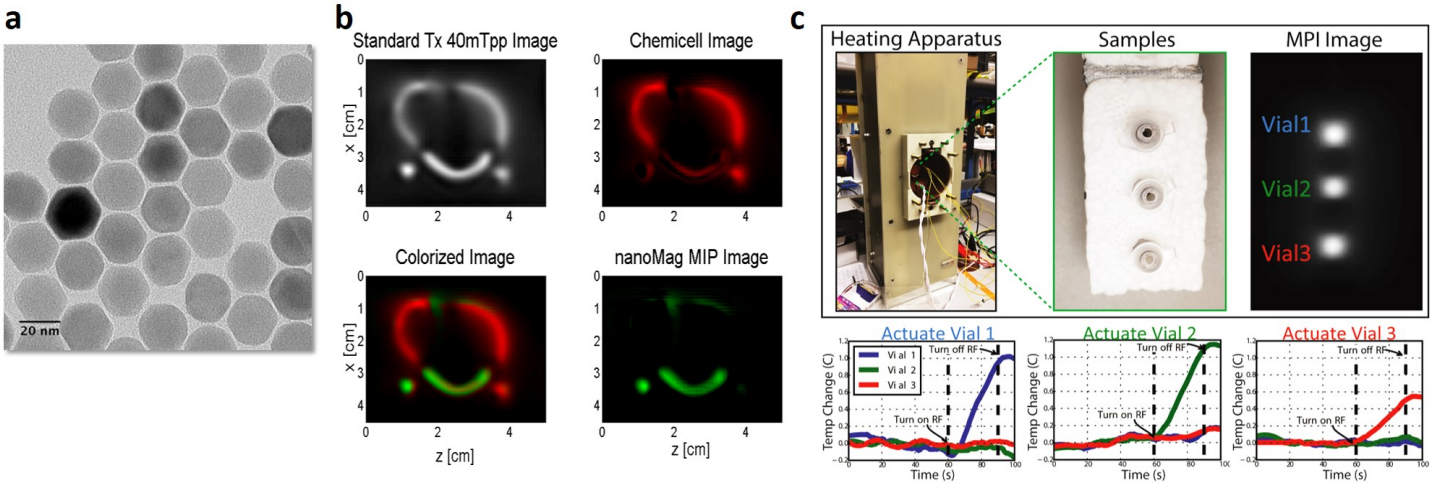

Figure 1: (a) TEM image of 20 nm core LodeSpin SPIOs. (b) Color-contrast MPI imaging of Chemicell and nanoMag MIP SPIO tracers in phantom. Combined colorized image is shown in bottom left. (c) Simultaneous MPI imaging and spatially control actuation of magnetic nanoparticle heat release by combining the selection gradient magnetic fields of MPI with an AMF (12 kA/m, 305 kHz).

Magnetic Hyperthermia

It is known that SPIOs can release heat in response to alternating magnetic fields (AMF) [4]. However, the conventional approach to heating is to apply the AMF to the entire sample or body, which can often lead to undesired and non-specific heating effects. Fortunately MPI systems can also be configured such that highly localized and specific targeted heating is possible. In order to demonstrate this concept, following imaging, the samples were placed in a heat actuation MPI device. The data shows the feasibility of localized heating by individually heating PCR vials filled with SPIOs and placing them in the FFL (field free line), which is used to capture the image, but can also be used to produce heat via hysteresis due to the AMF. Even though all PCR tubes experienced the same AMF fields, only the vial at the FFL is heated (Figure 1b). The rate of heat release is tunable and strongly frequency dependent, which allows imaging at low (e.g., 25 kHz) frequencies with insignificant heating while actuating heating at higher (e.g., 250 kHz) frequencies. These features could be used for thermal cancer therapy, theranostics, guided therapy and likely other applications.

Multi-Color MPI

Another unique enablement of MPI is multi-color imaging, which takes advantage of the differential magnetic properties between different sizes of SPIOs. These differences lead to the ability to measure distinct signals corresponding to particular particle types. For instance, large SPIOs are dominated by Brownian relaxation, whereas smaller SPIOs are dominated by Neel relaxation. These distinct differences can be exploited using two MPI acquisitions with different drive field amplitudes, making it possible to distinguish between Brownian versus Neel particles and leading to a multi-color image.

This technique also has the potential to detect changes in the particle environment such as viscosity, binding state or temperature. Essentially any relevant change in the particle spectrum can potentially form the basis for particle discrimination. In the future, multi-color MPI could possibly be used for interventional applications, to enable the discrimination between a particle-impregnated catheter and particles flowing in the vessels. Additionally, changes in targeted SPIO binding state such as particles bound to a lesion could be distinguished from those still suspended in the blood. Overall multi-color MPI could be useful for many applications in the fields of medical imaging, intervention and therapy.

Conclusion

MPI is one of the most promising imaging modalities introduced in the last decade. Here we describe some of the unique capabilities of this emerging platform technology and the SPIO properties utilized for different MPI methods. The innovations of the MPI system could make this scanner indispensable for a broad range of imaging applications.

References

1. IEEE Trans Med Imaging. 2012 Dec; 31(12):2335-42

2. Adv Mater. 2012 Jul 24;24(28):3870-7

3. IEEE Trans Med Imaging. 2013 Sep;32(9):1565-75

4. Adv Drug Deliv Rev. 2011 Aug 14; 63(9): 789–808

5. Environ Toxicol Chem. 2014 Mar;33(3):481-92

6. Sci Rep. 2015 Sep 11;5:14055

magnetic INSIGHT

1010 Atlantic Ave. Suite 100
Alameda, CA 94501, USA
info@maneticinsight.com
magneticinsight.com