Evaluating the Sensitivity of the Momentum ™ Magnetic Particle Imager for Ferucarbotran Iron Oxide Nanoparticles

Nicole Sarna[1], Leyda Marrero-Morales[1] , Angelie Rivera-Rodríguez[1], Ryan Degroff[2], Carlos Rinaldi[1,2]

[1]J. Crayton Pruitt Family Department of Biomedical Engineering, University of Florida, Gainesville, FL USA. [2]Department of Chemical Engineering, University of Florida, Gainesville, FL USA.

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INTRODUCTION

Magnetic Particle Imaging (MPI) is a novel biomedical imaging technology that enables non-invasive and unambiguous visualization of the distribution of biocompatible superparamagnetic iron oxide (SPIO) tracers with high sensitivity and resolution.

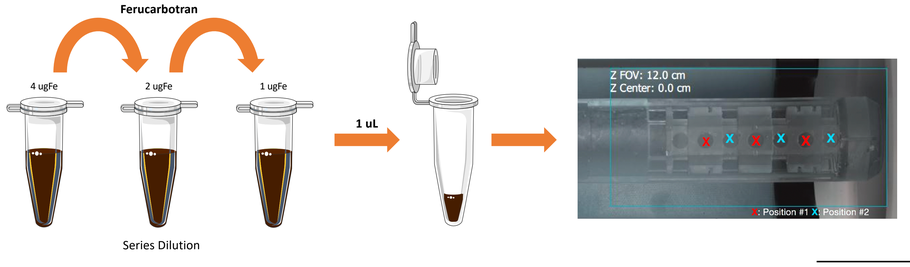
Characteristics:

- No tissue background
- Signal intensity is proportional to SPIO mass
- No artifacts arising from hypointense SPIO signal
- No signal attenuation by tissue depth
- No ionizing radiation
- Tracers have long shelf-life
- SPIO breaks down *in vivo*, with iron incorporation into hemoglobin and ferritin
- MPI images can be co-registered with other modalities

The Limit of Detection is the lowest amount of SPIO tracer the MPI can distinguish and quantify from the background signal. Determining these parameters will provide a better understanding of the instrument and its imaging capabilities.

Determining MPI sensitivity and resolution for different SPIO tracers ensures reliable data can be obtained, understood, and replicated. This will also enable optimization of tracers for MPI.

METHODOLOGY



- Series dilution of Ferucarbotran to image different concentrations of iron oxide particles
- MPI images taken in four imaging modes: Default, isotropic, high resolution and high sensitivity
- All samples prepared with 1uL of solution
- Samples measured in triplicate in two different positions in the MPI's 12.0 cm field-of-view (FOV)

Scan Modes	Field Gradient Strength	Time Acquisition
Default	5.7 T/m	3.3 min
Isotropic	5.7 T/m	3.4 min
High Sensitivity	3 T/m	3.5 min
High Resolution	6 T/m	6.4 min

RESULTS

Ferucarbotran Characterization

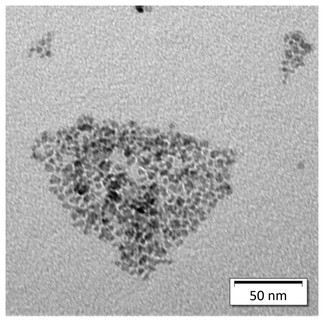


Figure 1. Transmission electron microscopy (TEM) image of Ferucarbotran

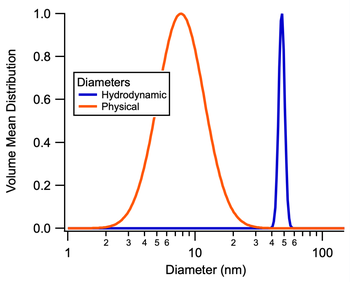


Figure 2. Dynamic light scattering (DLS) showing physical and hydrodynamic diameter of Ferucarbotran

MPI Sensitivity

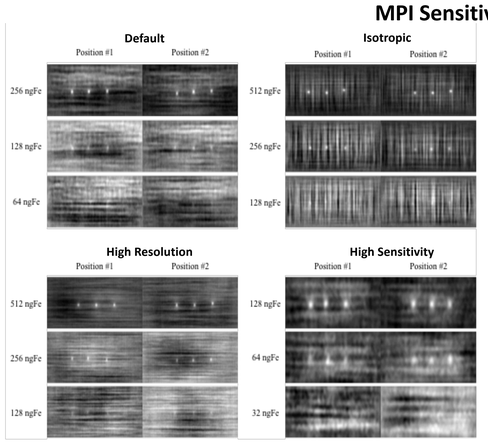


Figure 3. Images taken of decreasing concentrations of Ferucarbotran (in triplicate) in MPI scan modes, default, isotropic, high resolution, and high sensitivity. As the limit of detection is approached, the samples become less distinguishable from the background noise.

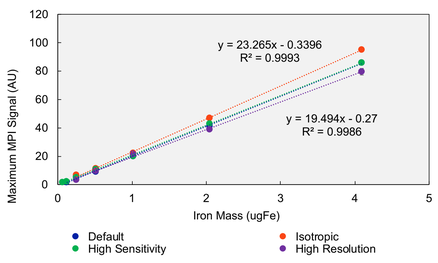


Figure 4. Graph demonstrates the linear relationship between MPI signal and iron mass.

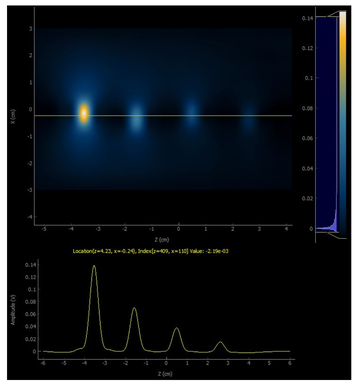


Figure 5. High sensitivity MPI scan of Ferucarbotran with decreasing iron mass from 4 µgFe to 0.5 µgFe. Image demonstrates MPI signal intensity that is proportional to iron mass and fully resolved signals.

Table 1. Limits of detection (LoD) for different MPI scan modes.

Scan Mode	LoD
Default	129.5 ngFe
Isotropic	159.1 ngFe
High Resolution	209.4 ngFe
High Sensitivity	38.4 ngFe

$$LoB = mean_{blank} + 1.645(SD_{blank})$$

$$LoD = LoB + 1.645(SD_{\text{low concentration sample}})$$

Figure 6. Equations used to calculate the limit of detection (LoD) [1]

MPI Resolution

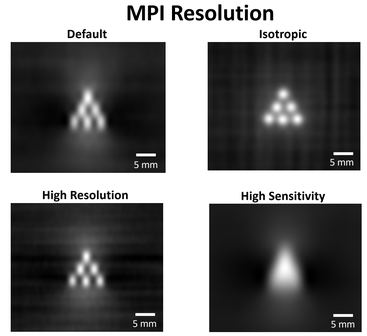


Figure 7. Images taken of 2µgFe/1 µL samples in 0.8mm ID/1.6mm OD capillary tubes in default, isotropic, high resolution, and high sensitivity scan modes. Samples resolved at a distance of 3.2mm in all scan modes except for high sensitivity.

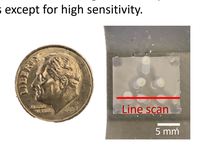


Figure 8. Resolution phantom used for resolution images in Figure 8. Distance from each sample is 3.2mm.

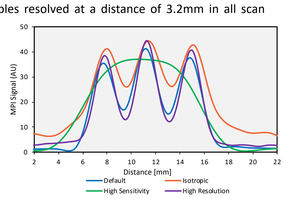


Figure 9. Resolution line scans from all scan modes in triangular phantom used in Figure 7.

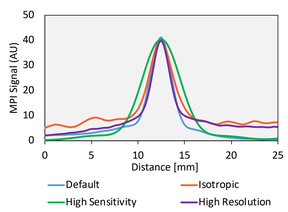


Figure 10. Scans of default, isotropic, high resolution, and high sensitivity MPI scan modes used to calculate the resolution.

Table 2. Calculated resolutions for default, isotropic, high resolution, and high sensitivity scan modes.

Scan Mode	Resolution
Default	2.24 mm
Isotropic	2.66 mm
High Resolution	1.88 mm
High Sensitivity	4.0 mm

CONCLUSIONS

- Scan modes with higher field gradient strength ('high resolution') have the lowest sensitivity, whereas scan modes with lower gradient field strength ('high sensitivity') have highest sensitivity
- Scan modes with higher field gradient strengths ('high resolution') have the highest resolution, whereas scan modes with lower field gradient strengths ('high sensitivity') have the lowest resolution

FUTURE WORK

- Optimize particle synthesis for better MPI resolution and sensitivity.
- Determine the sensitivity and resolution for transfected cells in MPI.

ACKNOWLEDGEMENTS

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REFERENCES

[1] D. Armbruster and T. Pry, "Limit of Blank, Limit of Detection and Limit of Quantification," *Clin Biochem Rev.* (2008)

[2] Graeser, M., Knopp, T., Szwargulski, P., Friedrich, T., von Gladiss, A., Kaul, M., Krishnan, K., Ittrich, H., Adam, G. and Buzug, T, "Towards Picogram Detection of Superparamagnetic Iron-Oxide Particles Using a Gradiometric Receive Coil," *Scientific Reports*, vol. 7, July 2017

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J. Crayton Pruitt Family Department of Biomedical Engineering