Positive Contrast Imaging of Micron-Sized Iron Oxide Particles

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Introduction: Recently, positive contrast methods have been proposed involving refocusing spins in the strong local magnetic field of superparamagnetic iron oxide (SPIO) particles [1-6]. The detection limit of this method depends on the diffusion of spins in the local microenvironment of the SPIO particles [7]. In this abstract, we investigate the possibility of imaging single SPIO particles by refocusing the spins in the surrounding environment. An agar gel model has been developed to evaluate various positive contrast pulse sequences.

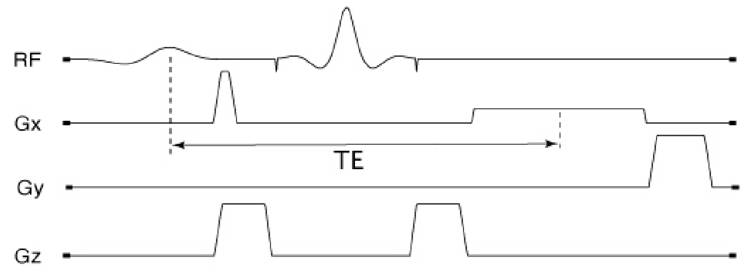

Fig. 1: Projection spin-echo pulse sequence diagram.

Methods: 0.2 µl of stock BioMag solution containing superparamagnetic iron oxide particles (45 mg/ml concentration, 2.5 g/ml particles, 10.5 µm mean diameter) (Bangs Laboratories, Inc., Fishers, IN) was suspended in a cylindrical 200 ml agar (5% by weight) (Sigma Chemical Co.) gel phantom.

Experiments were performed on a 1.5T GE Signa EXCITE scanner with a 3 inch surface coil. A conventional negative contrast GRE image was acquired in the coronal plane (TR/TE = 100/15ms, FOV = 12 cm^2, 256^2, NEX = 1, FA = 30°). Projection spin-echo (Fig. 1), on-resonance images were acquired in the coronal plane (TR = 800 ms, FOV = 20 cm^2, 256x128, NEX = 2, TE range = 14 – 400 ms). Projection spin-echo, off-resonance images were acquired in the coronal plane (same parameters as on-resonance, -600 Hz shift, TE range = 14 – 38 ms). Two NEX=40 off-resonance images (TE = 14, 18 ms) were also acquired.

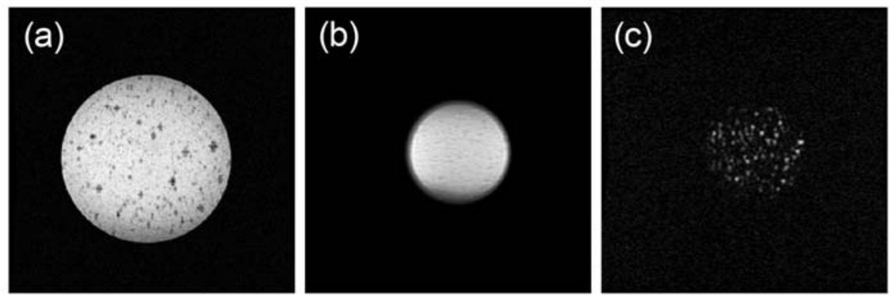

Fig. 2: SPIO contrast images. (a) Conventional GRE negative contrast image. The negative contrast regions display a typical dipole field shape. (b) Projection spin-echo, on-resonance image. (c) Projection spin-echo, off-resonance image displaying positive contrast in the region surrounding the SPIO particles.

Apparent T_2 maps for the on-resonance and off-resonance projection spin-echo sequences were produced by fitting each pixel collected at varying echo times to a single exponential model in Matlab (The MathWorks, Inc., Natick, MA).

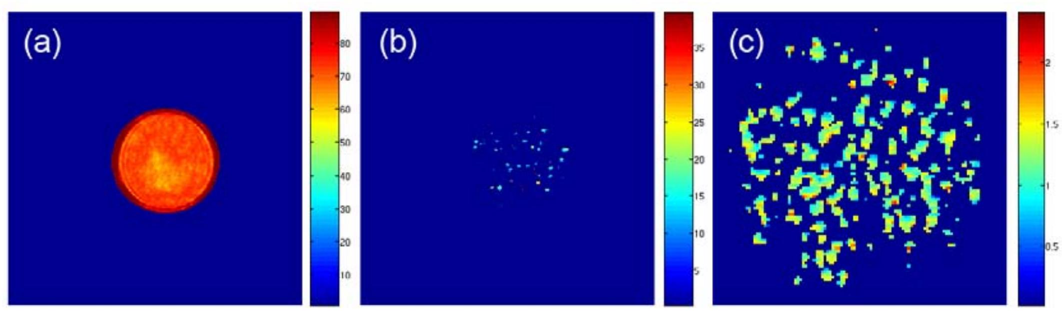

Fig. 3: T_2 maps. (a) T_2 map produced from 29 on-resonance projection spin-echo images. The bulk T_2 is approximately 70 ms. (b) T_2 map produced from 18 off-resonance projection spin-echo images. The T_2 in the region surrounding the SPIO particles ranges from 10-20 ms. (c) Ratio between off-resonance images (NEX = 40) with echo times of 14 and 18 ms.

Results and Discussion: Fig. 2 demonstrates that the signal from spins in the region surrounding SPIO particles with a mean diameter of 10.5 µm can be refocused into positive contrast. Fig. 3 shows that the apparent T_2 for spins near the SPIO particles is noticeably shorter in the off-resonance positive contrast image (approximately 20 ms) than in the on-resonance image (approximately 70 ms). Moreover, the peak apparent T_2 for each cluster in the off-resonance map appears to decrease as cluster size decreases. Fig. 3c displays a ratio between two images with an echo time difference of 4 ms. These results suggest that in order to refocus the signal from spins in the vicinity of even smaller SPIO particles into positive contrast, a short echo time sequence is required.

Conclusion: Positive contrast imaging of micron-sized superparamagnetic iron oxide particles has been demonstrated in an agar gel model using an off-resonance projection spin-echo sequence with a minimum echo time of 14 ms. Computed T_2 maps reveal a shorter apparent T_2 for spins near the SPIO particles in the off-resonance positive contrast image compared to the on-resonance image. In addition, the T_2 appears to correlate with particle size, and signal averaging reveals the presence of short T_2 spins, suggesting that a short echo time sequence is required in order to obtain positive contrast from smaller SPIO particles. A short echo time spin-echo sequence with a self-refocusing RF pulse is currently being developed.

References: [1] Coristine et al. Proceedings of the ISMRM, 163 (2004) [2] Cunningham et al. Magnetic Resonance in Medicine 53:999-1005 (2005) [3] Grant et al. Proceedings of the ISMRM, 2209 (2005) [4] Stuber et al. Proceedings of the ISMRM, 2608 (2005) [5] Carmichael et al. Proceedings of the ISMRM, 2613 (2005) [6] Foltz et al. Proceedings of the ISMRM, 2627 (2005) [7] Wade et al. Proceedings of the ISMRM, 1807 (2006)