Positive Contrast MR Imaging of Iron Oxide Nanoparticles with Simultaneous Suppression of Fat and Water Signals

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Introduction: The magnetic susceptibility difference between iron oxide based particulates and water spins induces spatially-dependent local magnetic field differences. Diffusion of water spins in the vicinity of these iron-based agents leads to irreversible phase loss amongst these spins which appear in MR images as signal voids (negative contrast). Recently, selective imaging of the off-resonant spins surrounding superparamagnetic iron oxide (SPIO) particles has been utilized to obtain 'positive contrast' by suppressing on-resonant spins that are sufficiently far from SPIOs [1,2]. This method may provide better visualization of the presence of SPIOs than negative contrast. However, a major limitation of positive contrast imaging (PCI) has been the difficulty of suppressing off-resonant fat, which has a -210 Hz shift relative to on-resonant water at 1.5 Tesla and is not suppressed by off-resonance frequency imaging alone. This work investigated a strategy of using a single pre-saturation pulse to suppress fat and on-resonance water spins simultaneously for slice-selective, fat-suppressed PCI with use of a magnetization prepared fast spin-echo (FSE) imaging sequence. Phantom experiments were performed to validate theoretical predictions.

Methods: The magnetic field perturbation (ΔB_z) a distance r from the center of a magnetic sphere of radius a in the presence of a static magnetic field B_0 is given by:

$$\Delta B_z = \frac{\Delta\chi}{3}\left(\frac{a}{r}\right)^3 \left(3\cos^2\vartheta - 1\right)B_0 ,$$

where $\Delta\chi$ is the susceptibility of the difference between the sphere and its surroundings and θ is the polar angle relative to B_0. From this equation it is clear that depending on θ, water protons sufficiently near the sphere experience either a positive or negative magnetic field perturbation relative to B_0.

We propose that saturation of on-resonant water (spins sufficiently distant from the sphere) and off-resonance fat spins may be performed simultaneously through application of a single radiofrequency (RF) pulse synthesized at a frequency between 0 Hz (water) and -210 Hz (fat) with adequate bandwidth (BW) to cover both the water and fat spectral peaks. While we suspect that such a pulse may saturate a fraction of spins experiencing negative ΔB_z, we hypothesize that one can still image off-resonant spins in regions with positive ΔB_z providing benefits of fat and on-resonant water suppression. Others have shown the utility of on-resonant water saturation during PCI [3].

Imaging experiments were performed in a 1.5 T whole-body clinical scanner (Sonata; Siemens Medical Systems, Erlangen, Germany). A flexible surface array coil was used for signal reception. A phantom consisting of distilled water, butter, and trace amounts of iron oxide nanopowder (Sigma-Aldrich, St Louis, MO) was assembled as shown in Fig. 1. Two-dimensional (2D) fast spin-echo (FSE) imaging was employed to generate MR images with positive contrast. Imaging parameters were: TR = 1 s, TE = 13 ms, echoes = 13, FOV = 10×10 cm^2, matrix = 256×256, NEX = 1, spatial resolution = 0.4×0.4×5 mm^3, imaging time = 20 s. FSE images were acquired at baseline (Fig. 1A), with system default fat saturation (Fig. 1B), and with simultaneous saturation of fat and water proposed here (Fig. 1C) (RF center frequency = -175 Hz, RF BW = 600 Hz, RF flip angle = 95°). Contrast-to-noise ratios (CNR) of SPIO-enhanced regions were calculated relative to water and fat.

Results & Discussion: Using the scheme proposed here, slice-selective positive contrast imaging was successfully performed with the benefit of both fat and water signal suppression (Fig. 1). CNR values are given in Fig. 2. This scheme may prove useful in detecting the presence of SPIOs in the vicinity of fat using 2D positive contrast MRI. Since fat saturated 2D FSE is well accepted as the gold-standard MR imaging method to visualize the arterial wall, this technique may be useful in plaque characterization studies that label activated macrophages with iron oxide particulates [4].

Conclusion: Slice-selective positive contrast imaging with simultaneous suppression of both on-resonant water and off-resonant fat appears feasible with 2D FSE imaging.

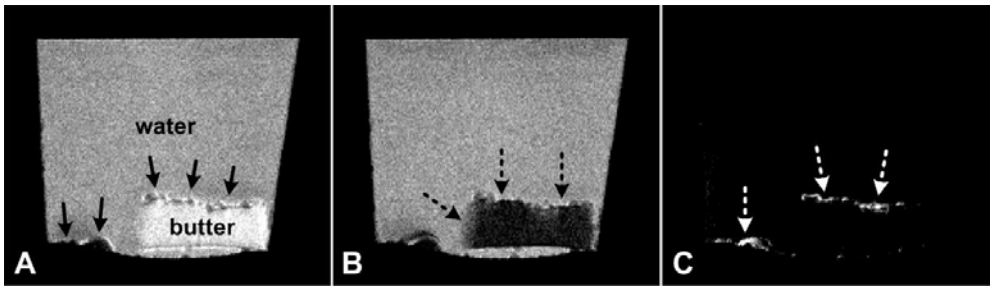

Figure 1. **A**, Baseline FSE image depicts the water and butter phantom. Iron oxide is present at the areas of focal signal loss (arrows). **B**, FSE image acquired with system default fat saturation. Note the suppression of the butter (dashed arrows). **C**, FSE image acquired with simultaneous suppression of both fat and on-resonant water. Note the positive contrast realized in the vicinity of the iron oxides (dashed arrows) and the excellent suppression of both fat and on-resonant water signal.

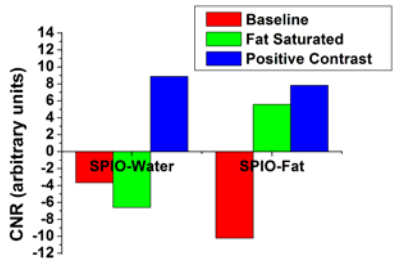

Figure 2. CNR between SPIO and water and fat signals in three images (A, B, and C from Fig. 1). With the proposed PCI technique, positive contrast was observed between SPIO and both water and fat.

References: [1] Cunningham CH et al. MRM. 2005; 53:999-1005
[2] Coristine et al. Proc ISMRM 2004, p. 163
[3] Gilson WD et al. Proc ISMRM 2005, p. 2621
[4] Ruehm SG et al. Circulation. 2001; 103:415-422