Fast Positive-Contrast Imaging of SPIO-Labeled Cells with Low-Angle Alternating-TR SSFP

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Introduction: Positive-contrast imaging of super paramagnetic iron oxide (SPIO)-labeled cells avoids problems associated with negative contrast such as other signal voids and partial volume effects [1-7]. Many techniques offer 2D imaging with thick slices and long scan times. A fast 3D alternating repetition time (ATR) SSFP [8] method with reliable on-resonant suppression has recently been introduced with preliminary phantom results [7]. In this work, we further analyze the signal characteristics, perform sensitivity experiments, propose a new technique to suppress fat in addition to the on-resonant signals, and present in vivo results.

Methods: The low-angle bSSFP profile has off-resonant peaks and reduced on-resonant signal [6]; however, the level of suppression is limited. We have proposed the use of ATR SSFP, which alternates between two TRs (TR1, TR2) to create a stop-band with a perfect central-null regardless of the tip angle and T1/T2 (Fig. 1). The level of suppression can be further improved by reducing τ = TR2/TR1, at the expense of reducing the range of frequencies contributing to positive contrast. Finally, the water-suppressed ATR image can be combined (through multiplication) with a fat-suppressed image acquired by shifting the stop-band to the fat resonance (Fig. 2). At the expense of slightly reduced SNR and spatially-varying noise, this combination reliably suppresses both water and fat signals.

Results: 3D GRE, bSSFP, and ATR images were collected on a 1.5 T GE scanner, with a knee coil (phantom) and a 3-inch coil (in vivo). For the GRE sequence: $\alpha=30^o$, TR=20 ms. The parameters for bSSFP and ATR were: TR=4.8 ms, 10 cm FOV, 0.6x0.6x0.8 mm^3 resolution, and a scan time of 0:32 s for both. For the phantom scans, $\alpha=15^o$, τ=0.15; and for the in vivo scans, $\alpha=5^o$, τ=0.07. Agar phantom images with varying concentrations (0.1 to 3 millions) of SPIO-labeled human stromal cells demonstrate the enhanced on-resonant suppression of ATR (Fig. 3). In vivo data were collected after injecting 1.5 and 3 million cells into the hind limbs of mice (Figs. 4,5). The background signal is robustly reduced when the water- and fat-suppressed ATR images are combined.

Conclusion: The low-angle ATR SSFP profile was manipulated to generate high-signal from SPIO-labeled particles while reliably suppressing the on-resonant and fat signals. The proposed method provides high-resolution fast positive-contrast imaging as demonstrated with the phantom and in vivo experiments.

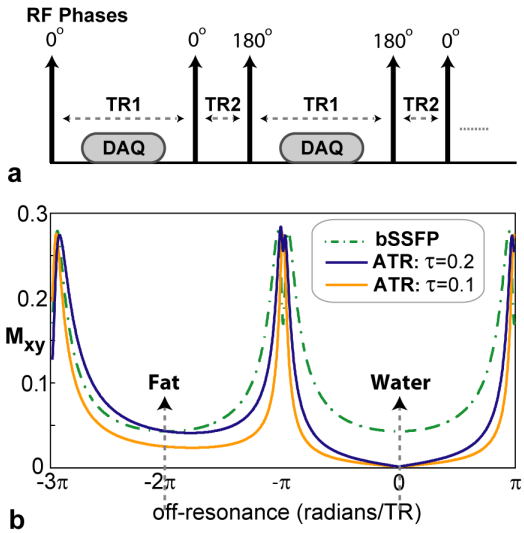

Figure 1. a: The ATR sequence diagram, where τ=TR2/TR1. **b:** Magnetization profiles (T1/T2=3) at $\alpha=5^o$ for bSSFP and ATR (τ=0.2,0.1).

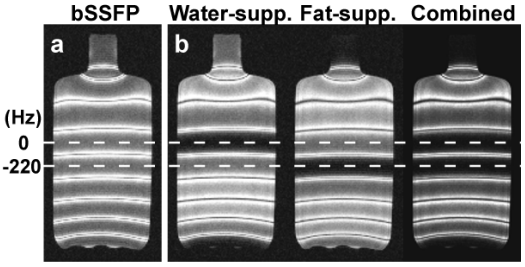

Figure 2. Water phantom with a vertical field gradient. ATR **(b)** suppresses water (0 Hz) better than bSSFP **(a)**. We can shift this stop-band to -220 Hz for fat suppression. Finally, the two ATR images can be combined to reduce both signals.

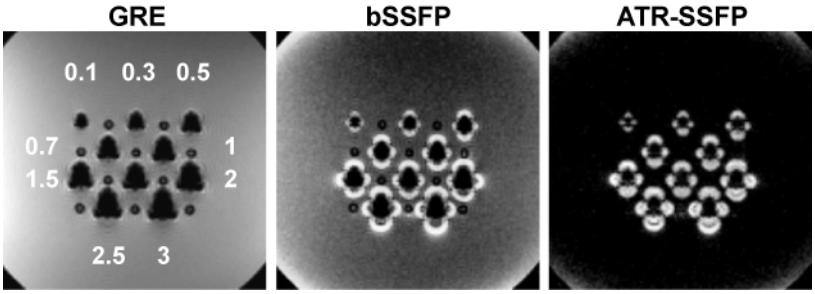

Figure 3. A phantom with varying concentrations (in millions) of SPIO-labeled cells was imaged with GRE, bSSFP and ATR. ATR achieves superior background suppression than bSSFP (identical display windowing for both).

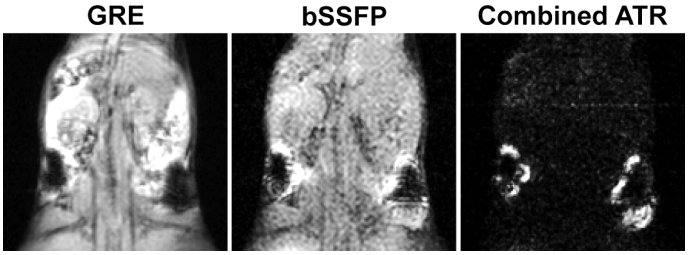

Figure 5. Coronal projections (over 4 slices) from another mouse scan. ATR achieves superior background suppression than bSSFP.

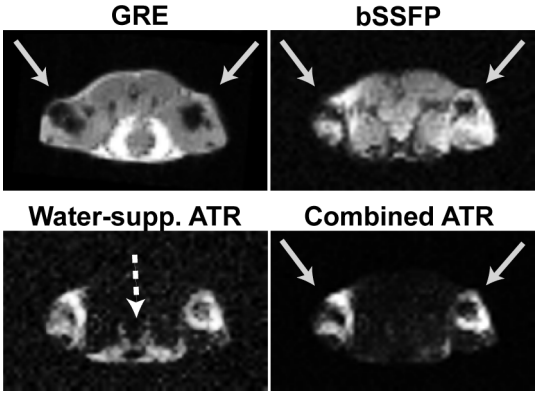

Figure 4. Axial slices from GRE, bSSFP, and ATR images of a mouse injected with SPIO-labeled cells into hind limbs (arrows). bSSFP cannot achieve sufficient background suppression. Water-suppressed ATR image yields residual fat (dashed arrow). The combined ATR image has reliable positive contrast.

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