Short T_2 Positive Contrast Imaging with Self-Refocused Spiral Pulse Sequence

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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]. Previous work has demonstrated that spins in the vicinity of SPIO particles have short T_2s relative to bulk water, and that there is a correlation between T_2 and particle size [8]. In this abstract, we investigate the possibility of imaging off-resonance short T_2 spins using a short TE pulse sequence containing a spectral self-refocusing radiofrequency (RF) pulse.

Methods: A self-refocusing RF pulse (Fig. 1a) was designed using the Shinnar-LeRoux (SLR) transform [9]. First, an SLR minimum phase RF pulse was designed (TBW = 8, $\delta_1 = 10^{-2}$, $\delta_2 = 10^{-3}$, FA 90°, PW 10 ms). The corresponding slice profile has undesired phase across the slice at the end of the pulse. Next, an all-pass filter is designed to add phase across the passband of the slice. This filter is applied to the alpha polynomial of the RF pulse, and the resulting alpha and beta polynomials are converted to the final RF pulse with the inverse SLR transform. The designed self-refocusing pulse produces a spin echo at the end of the pulse (Fig. 1b). A spiral pulse sequence (Fig. 1c) is used in conjunction with the self-refocusing pulse to acquire signal from short T_2 spins. Spiral trajectories allow for acquisition of the centre of k-space close to the spin echo time. The readout is placed 50 µs from the end of the RF pulse to minimize signal loss due to T_2* relaxation.

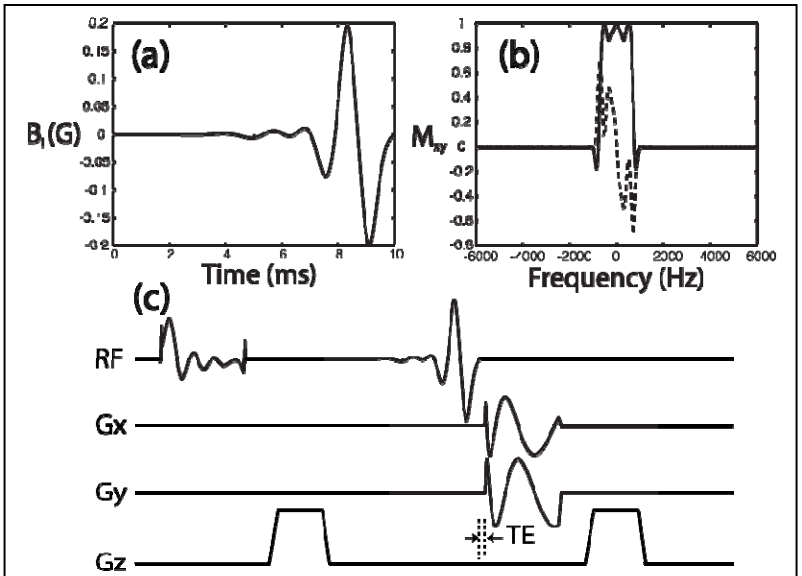

Fig. 1: Short echo time sequence. (a) A self-refocusing RF pulse is designed using the SLR transform. (b) Real (solid) and imaginary (dashed) components of the corresponding frequency profile. The signal is refocused at the end of the pulse, as shown by the relatively flat phase across the passband. (c) The pulse is placed inside a spiral sequence with a saturation stage to acquire the spin echo at the centre of k-space.

100 µl of Omniscan (Amersham Health, Inc.) was placed in the bottom of a microcentrifuge tube and inserted into a cylindrical 200 ml agarose (5% by weight) (Sigma Chemical Co.) gel phantom. A second phantom was prepared with the addition of 205.0 mg of $MnCl_2$ to shorten T_2.

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 = 20 cm, 256x128, NEX = 1, FA = 30°). Projection spin-echo, off-resonance images were acquired in the coronal plane (TR = 200 ms, FOV = 20 cm, 256x128, NEX = 4, TE = 14 ms, +600 Hz shift). Projection self-refocused spiral (Fig. 1c), off-resonance images were acquired in the coronal plane (TR = 200 ms, FOV = 20 cm, 1024x128 arms, BW = 125 kHz, NEX = 4, TE = 50 µs, +1100 Hz shift). The frequency shifts were chosen to suppress on-resonance water. The T_2 for spins at +600 Hz was determined by fitting a region of interest at varying TEs to a single exponential model in Matlab (The MathWorks, Inc., Natick, MA).

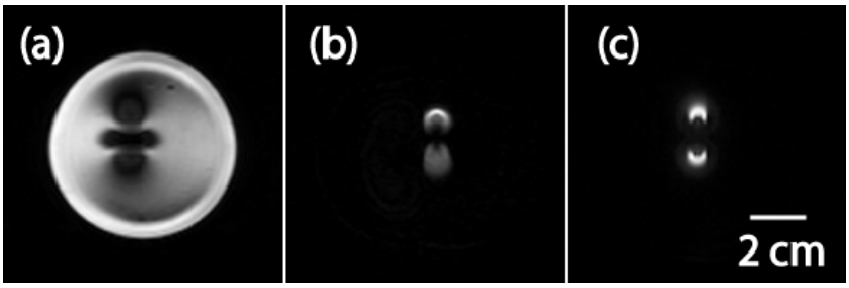

Fig. 2: Demonstration of positive contrast. (a) Conventional GRE negative contrast image. The dark region displays T_2* dephasing. (b) Projection spin-echo, off-resonance image displaying positive contrast of the dephased regions in (a). (c) Projection spiral, self-refocused image displaying similar positive contrast of the dephased region.

Results and Discussion: Fig. 2 demonstrates that the off-resonance signal from spins surrounding the gadolinium can be refocused using the self-refocusing pulse. The blurred region surrounding the refocused region is due to the transition width of the slice profile. Fig. 3 demonstrates that the self-refocused sequence can provide increased signal from off-resonance spins with shortened T_2 in an $MnCl_2$ doped phantom, compared to conventional spin echo images. The mean T_2 of the phantom at the off-resonance frequency was determined to be 3 ms.

Conclusion: Positive contrast imaging of off-resonance spins using a short echo time sequence with self-refocusing RF pulse has been demonstrated in an agar gel model using gadolinium as the field perturber. This short TE sequence is able to refocus increased signal from short T_2 spins compared to a projection off-resonance spin echo sequence.

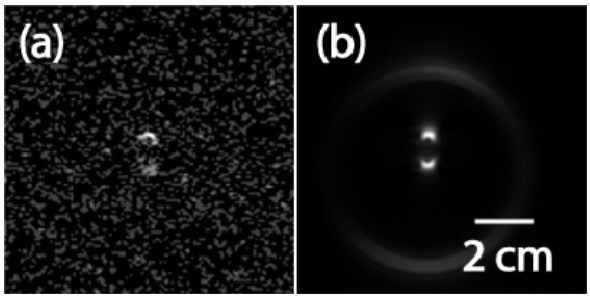

Fig. 3: Demonstration of positive contrast using a short TE self-refocusing pulse. A $MnCl_2$ doped agarose phantom with off-resonance T_2 of 3 ms was imaged with (a) spin-echo (TE = 14 ms) and (b) self-refocused spiral (TE = 50 µs) sequences. The ring around the refocused region is due to the 3-inch coil used.

References: [1] Coristine et al. Proc ISMRM, 163 (2004) [2] Cunningham et al. MRM 53:999-1005 (2005) [3] Grant et al. Proc ISMRM, 2209 (2005) [4] Stuber et al. Proc ISMRM, 2608 (2005) [5] Carmichael et al. Proc ISMRM, 2613 (2005) [6] Foltz et al. Proc ISMRM, 2627 (2005) [7] Wade et al. Proc ISMRM, 1807 (2006) [8] Lau et al. Proc ISMRM, 1369 (2007) [9] Pauly et al. IEEE Trans. Med. Im., 10:1 (1991)