

SSFP Diffusion prepared SSFSE

W. Dai¹, P. M. Robson¹, and D. C. Alsop¹

¹Radiology, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA, United States

Introduction

The bright signal of fluid and blood can affect tumor detection in screening applications. Diffusion weighted EPI is now frequently employed to attenuate these signals and highlight tumors. Gradient pulses can also be added to unbalanced SSFP sequences to attenuate the signals with motion. It has been demonstrated that SSFP sequence is strongly sensitive to self-diffusion or other motions. However, the diffusion sensitive SSFP sequence is difficult to combine with other contrasts and with slow acquisition speed. Here, we implemented SSFP diffusion as a preparation sequence before the image acquisition to eliminate signals with fast diffusion. This preparation can be flexibly combined with any image acquisition and with faster acquisition speed.

Theory

Following Wu et al (1), the steady state longitudinal magnetization just before each RF pulse $M_z(0^-)$ can be written (by the same convention as in the reference (1)) as $\langle M_z(0^-) \rangle = M_0 + c_0 E_{1,0}(TR)$. where c_0 and $E_{1,0}$ are a function of PD, T_1 , T_2 , the repetition time between two RF pulses (TR), gradient amplitude(G), gradient duration (τ), RF flip angle (α), and diffusion coefficient (D), as defined in the Wu et al paper. With assumed parameters T_1 of 1.3s, T_2 of 0.9 s, PD of 1, gradient amplitude of 4 G/cm, the magnetization as a function of gradient duration squared are shown in Fig. 1 for different diffusion coefficients (blue, $D=0.85 \times 10^{-3}$ mm²/s; green, $D=2$ mm²/s; red, $D=3$ mm²/s). It indicates that the prepared magnetization is sensitive to diffusion.

Methods

The preparation pulse sequence is shown as Fig. 2. Eight test tubes and in-vivo abdomen images with the proposed diffusion prep were studied on a GE 3 Tesla scanner with receive-only 8-channel array coils. Single-slice SSFSE image were acquired with a 128×128 matrix size. Nine test tubes (tube 1 to 8, with different concentration of MnCl₂ in water, monotonically increased T1 and T2 values, which was reported in (2); tube 9, with fat) were used to test the diffusion sensitivity (TR=25 ms, $\alpha=46^\circ$, G=4 G/cm, FOV=24cm, 4 mm slice thickness) by changing the gradient duration. The signal is normalized to the signal without prep RF pulses applied. The abdomen images were acquired with different TR, G, and α (FOV=34cm, 10 mm slice thickness, TE=31.8 ms, BW=83.3 kHz).

Results & Discussion

Phantom results show reduced signal as the gradient duration increased (Fig. 3). This indicates that the prep sequence has strong diffusion sensitivity. With large gradient duration, the signals from different tubes showed the expected monotonic decrease with T1 (perfect spoiling case in SSFP). The in-vivo abdomen images are shown in Fig. 4. Except for the shortest TR, 5 ms, the CSF and blood signals were well attenuated. Fat is quite prominent bright, so adding fat saturation sequence will be necessary to make the prep sequence more clinically attractive in tumor imaging. Comparison of in-vivo kidney signal as a function of TR of gradient duration and flip angle with theory indicates large diffusion sensitivity at TR = 10 ms.

Conclusion

Diffusion SSFP preparation shows promise for attenuating fluid and vascular signal in whole body screening studies.

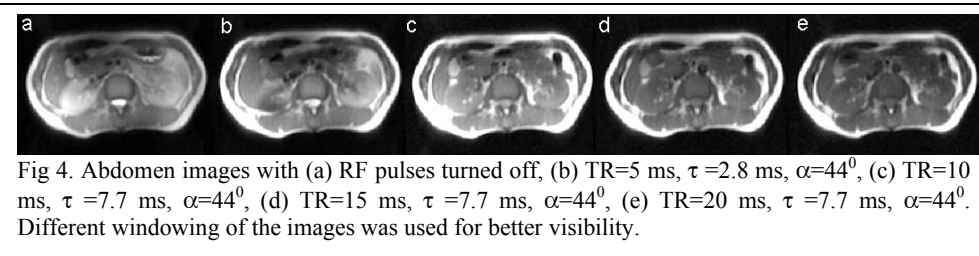


Fig 4. Abdomen images with (a) RF pulses turned off, (b) TR=5 ms, $\tau=2.8$ ms, $\alpha=44^\circ$, (c) TR=10 ms, $\tau=7.7$ ms, $\alpha=44^\circ$, (d) TR=15 ms, $\tau=7.7$ ms, $\alpha=44^\circ$, (e) TR=20 ms, $\tau=7.7$ ms, $\alpha=44^\circ$. Different windowing of the images was used for better visibility.

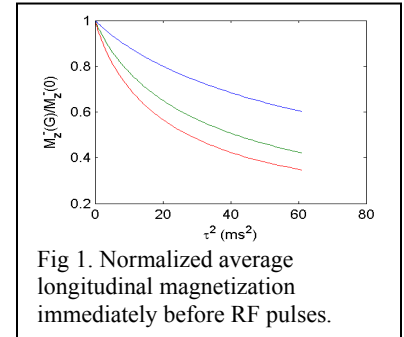


Fig 1. Normalized average longitudinal magnetization immediately before RF pulses.

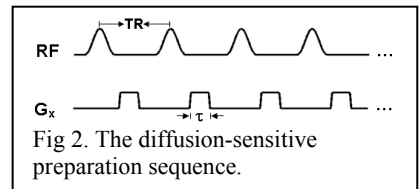


Fig 2. The diffusion-sensitive preparation sequence.

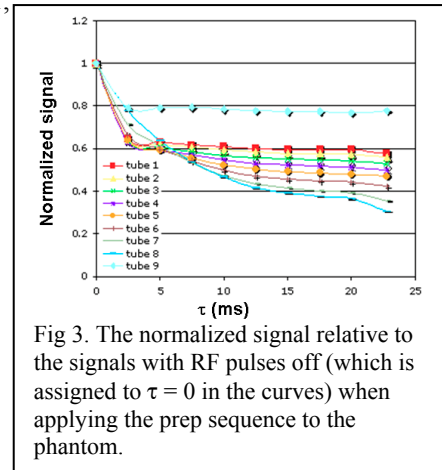


Fig 3. The normalized signal relative to the signals with RF pulses off (which is assigned to $\tau = 0$ in the curves) when applying the prep sequence to the phantom.

Reference

1. Wu et al, Journal of Magnetic Resonance 1990; 90:243-253.
2. de Bazelaire et al, Radiology 2004 ; 230 :652-659.