Self-Refocused Adiabatic Pulse for Spin Echo Imaging at 7T

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Introduction: 7T MR scanners offer the advantages of higher spatial resolution, increased spectral separation as well as enhanced contrast. Unfortunately, several technical issues at 7T, such as B_1 inhomogeneity and increased RF power deposition (as measured by the Specific Absorption Rate [SAR]), result in signal loss and limit the spatial coverage when using conventional imaging sequences. Apparent T_2 values are also effectively reduced for single echo sequences at ultrahigh field strengths [1,2]. Conventional Shinnar Le-Roux (SLR) [3] 180° pulses used in spin-echo sequences are highly susceptible to B_1 inhomogeneity. Adiabatic 180° pulses may be used instead of SLR pulses in spin echo sequences to provide B_1-insensitive refocusing. However, due to the quadratic phase across the slice profile generated by adiabatic pulses, adiabatic pulses must be used in pairs to refocus the phase of the resultant spin echo. This results in increased SAR and longer minimum echo times (TE's). The method to generate adiabatic pulses using the SLR transform given in [4] requires calculation of the α and β polynomials for the designed pulse. Once these polynomials are available, it is possible to design a matched-phase 90° pulse for an adiabatic 180° pulse so that a linear-phase spin echo may be produced without the use of a second 180° pulse. Similarly, a self-refocused adiabatic (SRA) 90°-180° pulse may be designed using the method described in [5]. Such pulse pairs provide the advantages of B_1-insensitive refocusing, reduced SAR when compared to pairs of refocusing pulses, shorter minimum TE values and linear-spin echo phase profiles. We have generated an adiabatic spin echo pulse with a phase-matched 90° pulse and used it to create an SRA pulse. The pulse was tested in simulations as well as in phantom and *in vivo* experiments.

Method: We used the method described in [4] to generate a 3 kHz, 12 ms, adiabatic 180° pulse with a peak RF amplitude of 12μT. The calculated β_{180} polynomial for the 180° pulse was used to design β_{90} for a matched phase 90° pulse [5]. RF amplitude and phase waveforms for matched-phase 90° and 180° pulses are shown in Figs. 1 (A,C) and (B,D), respectively. The calculated β_{180} and β_{90} were then used to generate an SRA pulse using the method in [5]. Because the self-refocused pulse is generated by combining the phase-matched 90° and adiabatic 180° pulses into one pulse, a considerably shorter TE than that possible with two separate pulses is achieved. The self-refocused pulse had a pulse duration of 24 ms, TE of 16.5 ms and a peak RF amplitude of 13.5 μT. RF amplitude and phase waveforms for the SRA pulse are shown in Figs. 1 E and F. The spectral profile for the SRA pulse was simulated for the pulse amplitude set to adiabatic threshold and 20% and 30% above the adiabatic threshold. Magnitude and phase of the simulated spectral profiles are shown in Figs. 1 G and H. Signal loss and distortion of the profile is similar to that of the matched-phase 90° pulse, demonstrating that B_1-insensitive refocusing is achieved. A 10% change in B_1 did not produce any significant change in the spectral profile. As the B_1 value is overdriven, some degradation of phase compensation occurs resulting in a small amount of quadratic phase across the profile.

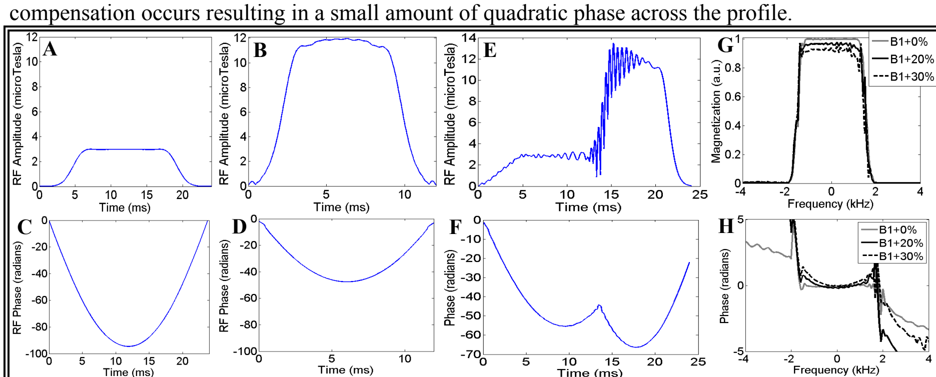

Figure 1: Amplitude and phase of the matched-phase 90° pulse (A,C), the corresponding adiabatic SLR 180° pulse (B,D) and a self-refocused adiabatic 90°-180° pulse (E,F). Magnitude (G) and phase (H) of the simulated spectral profile of the self-refocused pulse for B_1 values at and above the adiabatic threshold.

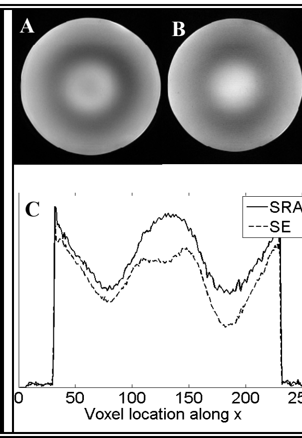

***Figure 2**: Image of a spherical agar phantom obtained using a (A) standard SE sequence and the (B) self-refocused adiabatic (SRA) pulse. Images have been compensated by the receive B_1 profile. Scan parameters are: TE/TR: 16.5/250ms, 256x256 grid, 5 mm slice, 22x22cm FOV. (C) Horizontal cross sections of images.*

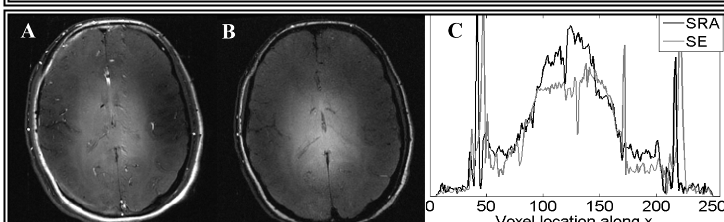

***Figure 3**: In vivo data: (A) standard SE sequence and (B) SRA pulse sequence. (C) Horizontal cross sections of images in (A) and (B). Scan parameters: TE/TR:16.5/250ms, 256x256 grid, 5 mm slice, 22x22cm FOV.*

Results: Refer to Fig. 2 for data from a spherical agar phantom scanned at 7T (GE Whole Body Magnet). Figures 2 A and B show images obtained using a conventional spin echo (SE) sequence and the SRA pulse to excite a 5 mm slice (TE/TR=16.5/250 ms), respectively. The receive B_1 profile was measured and images were compensated by the measured profile to remove receive shading. Figure 2 C shows the horizontal cross sections through these images. Greater signal loss is apparent for the SE sequence when compared to the SRA sequence, particularly at the center of the phantom where the SLR 180° pulse fails because it is overdriven. The signal loss for the SRA pulse will be similar to that for the phase-matched 90° pulse, which is not adiabatic but less susceptible to B_1 variation than a 180° pulse. A similar experiment was conducted *in vivo*. Figure 3 shows *in vivo* data from the brain of a normal volunteer scanned at 7T. Figures 3 A and B show images obtained using a conventional spin echo sequence and the SRA pulse sequence, respectively. The cross-sections through these images plotted in Fig. 3 C show that the SRA pulse achieves greater signal both at the center and edges of the brain where the B_1 field reaches its highest and lowest values, respectively. The *in vivo* images have not been scaled by the receive B_1 map.

Discussion: We have utilized an adiabatic SLR pulse to generate a matched-phase 90° pulse for spin echo imaging at 7T. Matched-phase 90° pulses for frequency-swept 180° pulses have been previously proposed using methods other than the SLR transform [6]. An SRA pulse is essentially a matched-phase pulse pair which has been combined into a single pulse by introducing zero delay between the 90° and 180° pulses. An SRA pulse was designed, implemented and validated with phantom and *in vivo* experiments. The SRA pulse, offers greater immunity to the B_1-insensitivity and reduced RF power deposition while enabling shorter echo times than sequences that use pairs of 180° adiabatic pulses to generate a spin echo. Due to the spin-locked state of the magnetization during the adiabatic 180° portion of the SRA pulse, a combination of T_2 and $T_{1\rho}$ contrast will be obtained.

References: [1] Yuh WT, et al. *Top Magn Reson Imaging.* 2006 Apr;17(2):53-61. Review. [2] Bartha R, et al. *Magn Reson Med.* 2002;47:742-750. [3] Pauly J, et al. *IEEE TMI* 1991; 10(1):53–65. [4] Balchandani P, et al. Proc. ISMRM 17. Honolulu, 2009; 178. [5] Balchandani P, et al. *Magn Reson Med.* 2009 Jul; 62(1):183-92. [6] Park J-Y, Garwood M. Proc. ISMRM 15. Berlin, 2007; 358. **Acknowledgements**: Lucas Foundation, NIH R01 MH080913 and GE Healthcare.