Selective Composite Adiabatic Refocusing Pulses for 3D RARE Imaging

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Introduction: Applications of selective adiabatic full passage (AFP) refocusing pulses has been limited by the inherent nonlinear phase dispersion (1). For this reason, selective AFP refocusing pulses are usually applied in pairs in spin echo (SE) pulse sequence so that the nonlinear phase dispersion produced by the first AFP pulse is canceled by the second AFP pulse to obtain a full echo signal (2). This pairing condition imposes a prolonged evolution time in fast spin echo pulse sequences, such as the adiabatic RARE (3). Recent preliminary results demonstrated that nonlinear phase dispersion associated with a selective AFP pulse can be effectively compensated using a pair of 90° HS_1 AFP pulses [4, 5]. To further advance that work, a composite selective adiabatic refocusing pulse with self-compensation capability for the nonlinear phase dispersion was designed for 3D RARE imaging in this study.

Experimental: The composite adiabatic refocusing pulse was constructed using two adiabatic half passage (AHP) waveforms (HS_1, R-factor = 20) generated by Bruker NMRSIM with phase reversal (pulse length = 3 ms, B_1(max) = 587 Hz, bandwidth = 5 kHz) (Fig.1). A bead phantom was prepared using 10 µm ORGASOL polymer beads mixed with 0.5 mM $MnCl_2$ and 5% agar in a 2.5 cm ID and 50 mL plastic tube. 3D images were acquired using a ^{1}H birdcage transmit/receive NMR probe-head (ID = 2.8 cm) and a RARE pulse sequence on an 11.7 T Bruker Avance 500 micro-imaging system equipped with a Bruker gradient coil (ID = 4 cm, gradient strength = 2.5 G/cm/A). An amplitude modulated selective refocusing pulse (hermite) from Bruker was also used in the pulse sequence to compare with the 3D images produced by the selective composite adiabatic refocusing pulse. Pulse parameters for the hermite refocusing pulse: pulse length = 1.267 ms, bandwidth = 2699.3 Hz. Scan parameters for the RARE sequence: TE/TR = 18 ms/5 s, effective TE = 56, 112 ms, RARE factor = 8, 16, matrix = 128 x 128 x 8, FOV = 4 cm, slab thickness = 8 mm, number of dummy scans = 2, number of average = 1, scan time = 5 m 20 s.

Results: In Figure 2, a full echo train was observed for the 3D RARE pulse sequence using the selective composite adiabatic refocusing pulse. The normalized slice profile amplitudes of the selective composite adiabatic refocusing pulse generated by the RARE sequence are significantly higher than that of the selective hermite refocusing pulses (Fig. 2). 3D images in Figure 3 show that the signal sensitivity and uniformity produced by the selective composite adiabatic refocusing pulse are significantly improved than that of the selective hermite refocusing pulses.

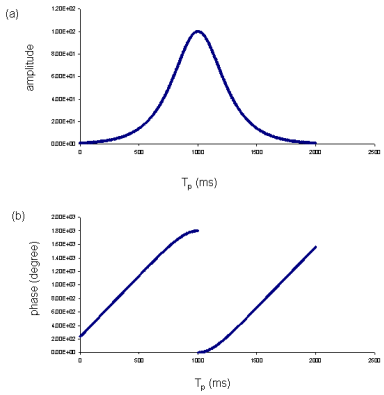

Figure 1. Amplitude (a) and phase (b) modulation of the selective composite adiabatic refocusing pulse.

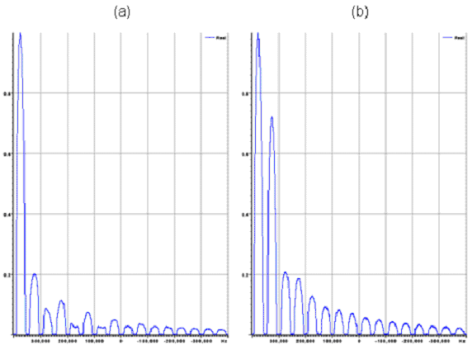

Figure 2. Slice profiles produced using (a) hermite and (b) composite adiabatic pulse in RARE

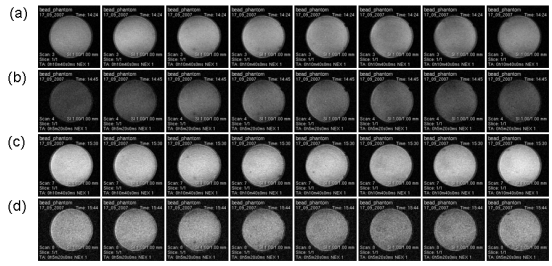

Figure 3. Axial images acquired using 3D RARE incorporated with selective refocusing pulses of (a) hermite (RARE factor = 8), (b) hermite (RARE factor = 16), (c) composite adiabatic pulse (RARE factor = 8), and (d) composite adiabatic pulse (RARE factor = 16).

Discussion: A compact composite selective adiabatic refocusing pulse has been successfully developed for uniform spin refocusing in 3D RARE imaging. Nonlinear phase dispersion is effectively compensated by the composite selective refocusing pulse because of the phase reversal of the AHP components. The short pulse length and the inherent compensation to the nonlinear phase dispersion make the selective composite refocusing pulse a good choice for multi-spin echo pulse sequences, such as RARE. The enhanced signal sensitivity and uniformity in the 3D images collected using the composite adiabatic refocusing pulse in comparison to that of the selective hermite refocusing pulse is attributed to the effective compensation of the off-resonance effect.

Reference and Acknowledgments: [1] D. Kunz, Magn. Reson. Med. 3 (1986) 377-384. [2] S. Conolly, G. Glover, et al, Magn. Reson. Med. 18 (1991) 28-38. [3] R. A. de Graaf, D. L. Rothman et al, NMR Biomed. 16 (2003) 29-35. [4] Z. Sun, Jay L. Zweier, Selective adiabatic refocusing pulse train for nonlinear phase dispersion and flip angle error compensation, in: Proceedings of the 16th Annual Meeting of ISMRM, Toronto, ON, Canada, 2008 (abstract 1324). [5] Z. Sun, Jay L. Zweier, Selective adiabatic refocusing pulse pair for 3D RARE, in: Proceedings of the 16th Annual Meeting of ISMRM, Toronto, ON, Canada, 2008 (abstract 3142). The author wishes to thank Dr. Amir Abduljalil for helpful discussions and the EPR Core Labs for the MRI scan time.