Selective Adiabatic Refocusing Pulse Pair for 3D RARE

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Introduction: Selective adiabatic full passage (AFP) pulses, such as hyperbolic secant (HS) pulses, have been applied for generating enhanced signal sensitivity and sharp voxel edges in MRI/MRS fields [1-3]. However, nonlinear phase dispersion associated with selective AFP pulses has limited AFP pulses for being used in multi-spin-echo pulse sequences, such as RARE, because a pair of identical 180° selective AFP pulses separated by extended evolution time is required to eliminate the nonlinear phase dispersion and to produce an echo [4]. This causes elongated echo time (TE) and low echo amplitude. One possible solution to the problem is to use a pair of 90° HS AFP pulses that cancel each other's nonlinear phase dispersion yet does not require evolution time to produce an echo [5]. Furthermore, off-resonance effect associated with selective AFP pulses could be compensated if the two 90° HS AFP pulses have alternate frequency sweep (AFS) directions [6]. In this study, we developed a selective AFS-AFP refocusing pulse pair using two 90° HS1 AFP pulses, and validate it using a 3D RARE pulse sequence on a phantom.

Methods: Hyperbolic secant (HS1_R20) AFP RF waveforms were generated using Shapetool from Bruker Bio-spin. The AFS-AFP pulse pair consisted of two 90° HS1_R20 pulses (pulse length = 4 ms, band width (BW) = 4 kHz, B1(max) = 587.259 Hz, pulse power = 8 dB) separated by a time delay of 4ms. For the first 90° HS1_R20 pulse, RF frequency swept from the high effective field (ω_{eff}) to the low field, whereas for the second 90° HS1_R20 pulse, RF swept reversely. A 3D RARE sequence from Bruker was modified to incorporate the selective AFS-AFP refocusing pulse pair (Fig. 1). The 3D RARE sequences incorporated with a selective hermite refocusing pulse (pulse length = 1.267 ms, BW = 2699.3 Hz) and a single selective 180° HS1_R20 AFP refocusing pulse (pulse length = 4 ms, BW = 4 kHz, B1(max) = 2.3 kHz, pulse power = 0 dB) were also used to acquire images, respectively. The 90° excitation was executed by a hermite pulse (pulse length = 2 ms, BW = 2700 Hz) (Fig. 1). A bead phantom was prepared using a plastic tube (2.8 cm OD) containing agar gel (5%) mixed with 10 µm ORGASOL polymer beads and 0.5 mM $MnCl_2$. Axial images were obtained on a 11.7 T Bruker Avance-500 micro-imaging magnet with a Bruker gradient coil (4 cm ID, 2.5 G/cm/A gradient strength) using a ^{1}H Miro2.5 birdcage probe-head (3 cm ID). Imaging parameters: TE/TR = 18ms/5s, Effective TE = 56 ms, RARE factor = 8 and 16, matrix size = 128x128x8, FOV = 4 cm, slab thickness = 8 mm, 2 dummy scans, 1 average, scan time = 5 m 20 s to 10 m 40 s.

Results: In Figs. 2A and 2B, the second echo amplitude generated the AFS-AFP pulse pair is significantly greater than that of the hermite pulse, whereas other echoes' amplitude after the second echo are either comparable to or greater than those of the hermite pulse. Consecutive echoes were produced by the selective AFS-AFP pulse pair (Fig. 2C) in contrast to that of the single selective 180° AFP refocusing pulse (Fig. 2D), where the even numbered echo amplitude was greatly reduced. Images obtained using the selective AFS-AFP refocusing pulse pair (Fig. 3A) shows significantly greater signal intensity and uniformity than those of the selective hermite refocusing pulse (Fig. 3B), whereas images acquired using a selective 180° AFP refocusing pulse shows severe signal loss (Fig. 3C).

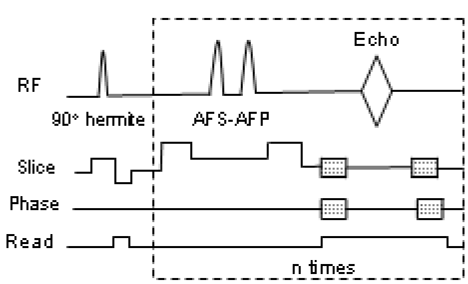

Figure 1. Modified RARE sequence incorporated with selective refocusing AFS-AFP pulse pair.

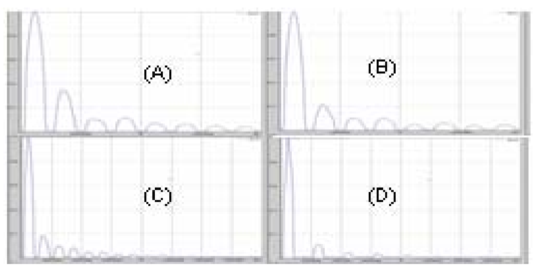

Figure 2. Normalized real-value echo amplitude generated by the 3D RARE sequence incorporated with AFS-AFP (A, C), hermite (B), and single AFP selective refocusing pulses for RARE factors of 8 (A, B) and 16 (C, D), respectively.

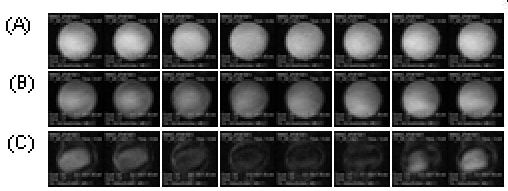

Figure 3. Axial images obtained using 3D RARE (RARE factor = 8) using AFS-AFP (A), hermite (B), and single 180° AFP (C) refocusing pulses.

Discussion: A compact selective AFS-AFP refocusing pulse pair has been successfully applied to a 3D RARE sequence with regular RARE factors. The enhanced image signal intensity and uniformity in comparison to that of the selective hermite refocusing pulse and to that of the single selective 180° AFP refocusing pulse is attributed to the effective compensation for the nonlinear phase dispersion and off-resonance effect using the selective AFS-AFP refocusing pulse pair.

References and Acknowledgments: [1] M. Garwood, et al, J. Magn. Reson. 153 (2001) 155-177. [2] R. Bartha, et al, Magn. Reson. Med. 47 (2002) 742-750. [3] S. Michaeli, et al, Magn. Reson. Med. 53 (2005) 823-829. [4] S. Conolly, et al, Magn. Reson. Med. 18 (1991) 28-38. [5] D. Kunz, Magn. Reson. Med. 4 (1987) 129-136. [6] Z. Sun, et al, Proc. 14th Annual Meeting of ISMRM, Seattle, WA, USA, 2005 (Abstract 2999). The authors wish to thank Dr. Amir Abduljalil for helpful discussions and EPR Core Labs at the OSU for MRI scan time.