T2-Weighted Spin Echo Pulse Sequence That is Sensitive to Restricted Diffusion

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Introduction: T_2-weighting generated by the spin echo (SE) pulse sequences utilizing selective adiabatic full passage (AFP) pulse trains has been used to generate microscopic susceptibility contrast in Human brains [1]. The contrast mechanism is ascribed to the spin diffusion weighting in the presence of local magnetic susceptibility gradients [1]. In a similar approach, phantom study has demonstrated that enhanced diffusion weighting can be achieved by incorporating selective AFP pulse trains into a diffusion weighted SE sequence [2]. Theoretical derivation [2] indicated that selective AFP pulse trains can increase diffusion weighting when incorporated into a conventional Stejskal-Tanner (S-T) diffusion weighted SE sequence [3]. In this study, diffusion weighting generated by the AFP pulse trains in a conventional T_2-weighted SE sequence without using diffusion pulsed gradients was investigated experimentally on a multi-compartment and multi-medium phantom for probing restricted diffusion.

Methods: Imaging experiments were performed on an 11.7 T Bruker Avance 500 system with a Bruker gradient coil using a birdcage transmit/receive RF coil (ID = 2.8 cm). A SE sequence was modified by incorporating two selective AFP pulse trains separated by a time delay (τ) at the symmetric positions of a hermite refocusing pulse (T_p=1.3 ms, BW=2.7 kHz). AFP pulse trains were constructed using n hyperbolic secant (HS_1) AFP pulses with single- and alternate-frequency sweep (SFS and AFS) directions in adjacent AFP pulses, respectively (R-factor = 20, T_p = 3.5 ms, B_1(max) = 2.6 kHz, n = 2, 4). A phantom consisted of a plastic tube (ID = 1.5 cm) and three glass vials (ID = 5 mm) was bounded together to form four compartments. The plastic tube was filled with a mixture of 10 micron ORGASOL polymer beads and 50 μM $MnCl_2$ dissolved in 5% agar and formed compartment 1 (ROI-1) (Fig.1). The three vials contained 50, 100, and 150 μM $MnCl_2$ dH_2O solutions and formed compartments 2 to 4 (ROI-2 to ROI-4), respectively. Single slice images were acquired from the phantom by varying TE using the customized SE sequence containing nAFP-SFS/AFS pulses for apparent T_2 measurements (TE = 26-46/40-60 ms, τ = 14–37/21-41 ms for n = 2/4, TR = 2 s, FOV = 40 x 40 mm^2, Matrix = 128 x 128, slice thickness = 5 mm, 4 ave, 2 dummy scans, MLEV-4 phase cycling, scan time = 17m4s). T_2 measurements were also performed using a Bruker CPMG sequence (num echoes = 8, Eff. TE = 10 – 80 ms in steps of 10 ms, other parameters the same as above) and a conventional SE sequence (TE = 10 – 60 ms in steps of 10 ms, other parameters the same). Apparent T_1 time constants for each compartment of the phantom were measured using a balanced SSFP sequence from Bruker for avoiding T_1 saturation in the T_2 and diffusion measurements (TE/TR = 2/4 ms, scan repetition time = 10 s, TI = 79.5 ms, segment time w/o separation = 128/64 ms, num frames = 60, num segment = 8, 10 dummy scans, alpha_2 = 0.5xTR, scan time = 5m20s, other parameters the same). The apparent diffusion coefficient (ADC) values were acquired for the phantom using the standard S-T DWI pulse sequence from Bruker (TE/TR = 20/2000 ms, δ = 5 ms, Δ = 8.52 ms, b-value = 57 – 472 s/mm^2 steps of 46 s/mm^2, 1 ave, scan time = 4m16s, other parameters the same). Apparent T_2 and ADC values were calculated from the logarithm of the average signal intensity (ln(SI)) as a function of TE and b-value, respectively. Apparent T_1 values were obtained using the Bruker IrTruFispMap macro.

Results: The measured apparent T_1, T_2, and ADC values are listed in Table 1. The apparent T_2 in ROI-1 measured using the nAFP-SFS/AFS-SE sequence is significantly greater than those in other compartments. In contrast, the apparent T_2 in ROI-1 measured using the conventional SE and CPMG sequences is either significantly lower or very close to that in ROI-2, respectively. The apparent T_2 in ROI-2 to 4 is decreased as n is increase from 2 to 4, whereas the apparent T_2 in ROI-1 is almost unchanged with n. For the same n, the apparent T_2 generated by the AFS pulse train in ROI-4 is significantly lower than that of the SFS pulse train. The ADC value in ROI-1 is significantly lower than those in ROI-2 to 4. T_2-weighted images are shown in Figure 1 for contrast effect comparison.

Table 1. The measured apparent T_1, T_2, and ADC values for the phantom

ROI	T_2 (ms)						T_1(ms)	ADC (10^{-3} mm^2/s)
	2SFS	2AFS	4SFS	4AFS	SE	CPMG		
1	14.1 ± 0.8	14.1 ± 0.2	14.6 ± 0.9	14.2 ± 1.2	30.6 ± 1.1	37.2 ± 1.2	370.9 ± 11.8	1.66 ± 0.03
2	9.2 ± 0.2	9.0 ± 0.1	8.7 ± 0.1	8.3 ± 0.1	41.8 ± 0.9	35.8 ± 0.8	384.3 ± 8.1	2.44 ± 0.02
3	8.2 ± 0.1	7.8 ± 0.2	7.0 ± 0.3	7.0 ± 0.1	25.9 ± 0.4	24.6 ± 0.6	243.8 ± 3.4	2.47 ± 0.03
4	8.2 ± 0.6	6.8 ± 0.3	7.1 ± 0.3	5.7 ± 0.2	20.1 ± 0.7	20.3 ± 0.6	178.3 ± 3.0	2.65 ± 0.23

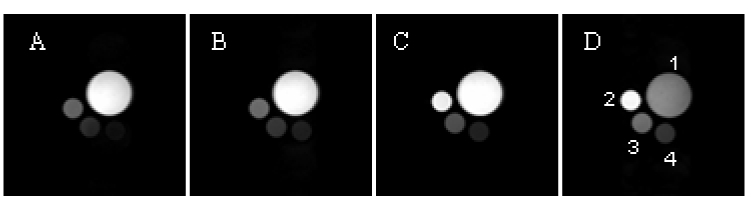

Figure 1. Phantom images collected using 4AFP-AFS/SFS-SE (A/B), CPMG (C), and SE (D) sequences at TE = 55, 80, and 60 ms, respectively.

Discussion: Experimental results from the T_2 and diffusion measurements demonstrate that the nAFP-SFS/AFS-SE sequence generates T_2-weighted contrast that is sensitive to restricted diffusion in the medium in comparison to those of the conventional SE or CPMG sequences.

References: [1] B. Bartha, et al, Magn. Reson. Med. 47 (2002) 742-750. [2] Z. Sun, et al, J. Magn. Reson. 188 (2007) 35-40. [3] E.O. Stejskal, et al, J. Chem. Phys. 42 (1965) 288-292.