Adiabatic Selective Excitation in Single-Slab 3D Turbo Spin Echo Imaging

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Introduction: Spatially selective single-slab three-dimensional (3D) turbo spin echo (SE) sequence (1) has been recently developed to increase imaging efficiency employing a highly selective excitation radio-frequency (RF) pulse, very short non-selective refocusing pulses, and variable low flip angles with long echo trains. Despite the enhanced imaging efficiency, this sequence is sensitive to spatially varying B_1 amplitude, in particular, at high field, generating non-uniform signal-intensity or contrast over the field-of-view. The purpose of this work is to develop a version of single-slab 3D turbo SE sequence less prone to B_1 inhomogeneity without compromising the imaging efficiency using composite adiabatic selective excitation.

Sequence Design: Both excitation and refocusing RF pulses in single-slab 3D turbo SE sequence are vulnerable to changes in B_1 amplitude if the pulses are modulated only by amplitude. The hypothesis of this work is that it would be critical to achieve uniform rotation from the longitudinal direction to the transverse plane in reducing B_1inhomogeneity. For slab-selection, composite three frequency-modulated (adiabatic) pulses similar to (2) were employed wherein spins initially in the longitudinal direction uniformly tip into the transverse plane by non-selective adiabatic-half-passage (AHP) pulse and then in-slab spins are refocused while out-of-slab spins are de-phased by a pair of selective adiabatic-full-passage (AFP) pulses (Fig. 1). The AHP pulse was designed using numerically-optimized-modulation (NOM) procedures (3) with sin / cos input functions to achieve maximal B_1 insensitivity. The AHP pulse parameters were: duration, 5.12 ms; maximum B_1 amplitude (B_{1max}), 16-23 μT; maximum pulse frequency, 1.3*B_{1max}; B_1 scaling range in NOM, 0.2-10. The AHP was also designed considering Carr-Purcell-Meiboom-Gil (CPMG) condition where the orientation of on-resonant magnetizations following the composite adiabatic excitation is matched with that of the refocusing pulse axis. The AFP pulse was a selective inversion pulse (duration, 10.24 ms; bandwidth, 2 kHz) where pulse amplitude and phase were modulated by sech / tanh functions (4). After the slab-selection, non-selective refocusing pulses were applied with variable flip angles that were calculated using an inverse solution of the Bloch equation to yield tissue-specific prescribed signal evolutions (1). Due to the difference of slab selection between excitation (selective) and refocusing (non-selective) pulses, out-of-slab free-induction-decay (FID) signals alias into the slab resulting in sharp-edge artifacts. To avoid this problem, a two-step phase cycling was performed in two acquisitions where the phase of refocusing pulses is incremented by 180° between excitations, resulting in cancellations of out-of-slab FID signals in averaging process.

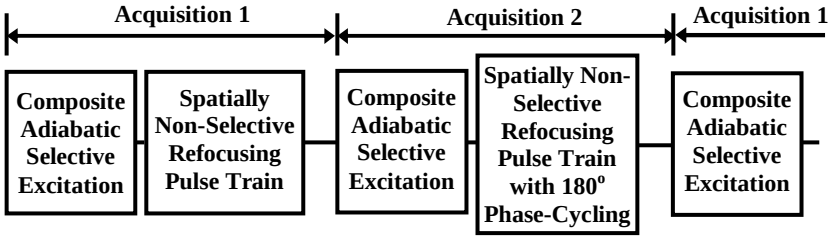

Fig. 1. Schematic of adiabatic selective excitation in single-slab 3D TSE sequence

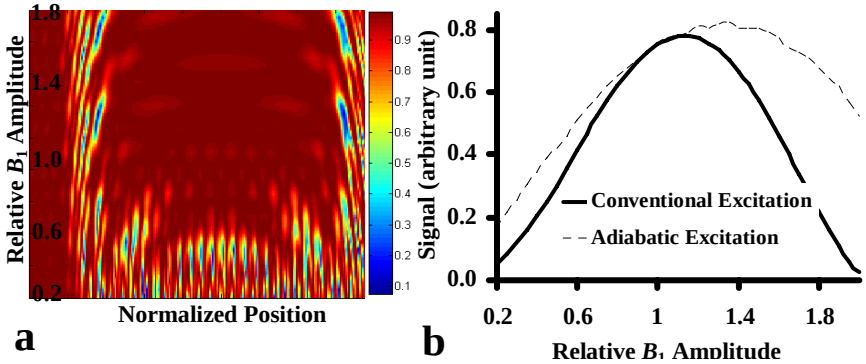

Fig. 2. Simulated slice profile with varying B_1 amplitude relative to its nominal value following adiabatic excitation (a) and simulated signal profile in the center of slab at TE_{eff} with varying B_1 amplitude for conventional and proposed excitations (b)

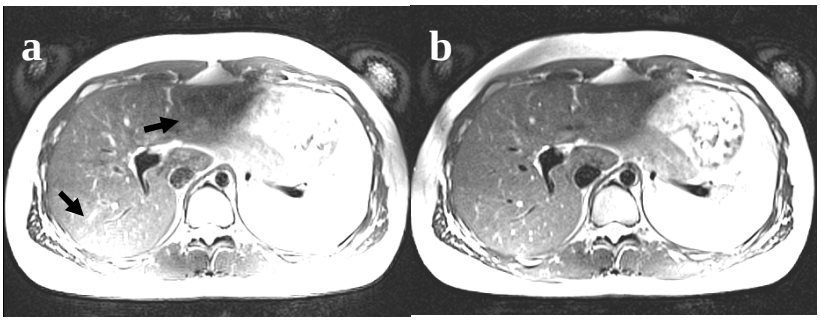

Fig. 3. Comparison of conventional (a) and proposed (b) excitations in single-slab 3D Turbo SE sequence. Note that image intensity is relatively uniform and image details are visible in (b) as compared to (a).

Materials and Methods: Numerical simulations of the Bloch equation (relaxation ignored) were performed to investigate the B_1 sensitivity of the conventional (1) and proposed pulse sequences following the excitation and the effective time of echo (TE_{eff}), respectively. Abdominal imaging was performed in volunteers at 3.0 T (MAGNETOM Trio, Siemens Medical Solutions, Erlangen, Germany) whole-body MR scanners using conventional and proposed sequences for comparison. The simulation and imaging parameters were: TR/TE_{eff}, 4000/125ms; ETL,120; ESP,3ms; FOV,188x250mm^2; matrix,256x256; thickness,3mm; partitions,40.

Results: Simulated slice profile demonstrates that actual flip angle, 90°, is achieved in relative B_1 amplitude range higher than 0.6 following the composite adiabatic excitation (Fig. 2a). Simulated signal profile at TE_{eff} shows that the composite adiabatic excitation generates higher signal than the conventional excitation over the entire given range of relative B_1 amplitude. Abdominal imaging verifies the simulation results, showing severe intensity variation over the liver in the conventional excitation (Fig. 3a) while relatively uniform signal intensity in the composite adiabatic excitation (Fig. 3b).

Conclusion: We developed an adiabatic version of spatially selective single-slab 3D turbo SE sequence to reduce the sensitivity to changes in B_1 amplitude. In addition to the reduction of B_1 inhomogeneity, the proposed sequence provides flexible T2 contrast mechanism for variable refocusing flip angles by adjusting echo spacing between a pair of AFP pulses without separate T2-preparation. Outer volume suppression is excellent due to severe de-phasing of out-of-slab spins. This technique is expected to widen clinical applications of single-slab 3D turbo SE sequence.

References: [1] Mugler et. al., Proc ISMRM, 2004, p695, [2] Conolly et. al., MRM, 1991, 18(1): 28-38, [3] Ugurbil et. al. JMR, 1988, 80:448-469, [4] Silver et. al. Phys Rev A, 1985, 31(4):2753-2755