T1-Optimized Single-Slab 3D Turbo Spin Echo Imaging with Long Echo Trains

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Introduction: T1 contrast is typically acquired using multi-slice two-dimensional (2D) or multi-slab 3D spin echo (SE) imaging. These conventional methods are problematic in acquiring high-resolution due to long acquisition time, imperfect slice profile, or high power deposition. Single-slab 3D SE imaging was recently introduced employing a long echo train to address the problems (1,2). However, T1 contrast becomes sub-optimal with the long echo train: 1) T2-weighted signals gradually develop along the echo train, and 2) centric-ordering of phase-encoding (PE) lines results in image blurring. In this work, we propose a new scheme of T1-optimized single-slab 3D SE pulse sequence with a long echo train.

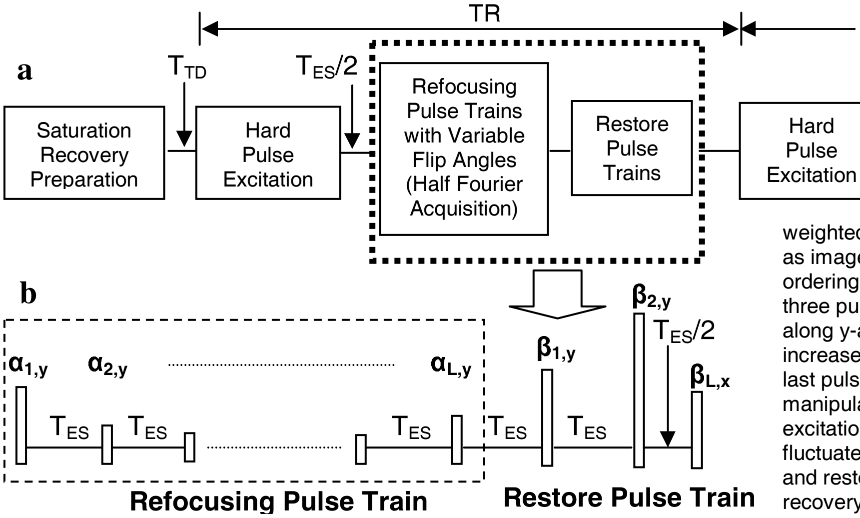

Fig. 1. Schematic of proposed turbo SE sequence for T1 contrast (a) and detailed view of refocusing and restore pulse trains (b).

Materials and Methods: Figure 1 represents a schematic of the proposed T1-optimized pulse sequence with a long echo train. Spatially non-selective excitation pulse is applied and followed by refocusing pulse train with variable flip angles. Both the excitation and refocusing pulses are hard pulses with short duration to achieve short time of echo spacing (T_{ES}). The refocusing flip angles are calculated using tissue (gray matter) - specific prescribed signal evolution (1). To prevent T2-weighted signals from being developed along the echo train as well as image blurring, half partial Fourier acquisition is used with linear ordering of PE lines (Fig.1a). A restore pulse train that consists of three pulses is applied (Fig. 1b). The first two pulses are applied along y-axis and use relatively high flip angles ($\beta_{1,y}$ and $\beta_{2,y}$) to increase the refocusing of remnant transverse magnetization. The last pulse is applied along x axis and its flip angle ($\beta_{L,x}$) is adjusted to manipulate the difference of longitudinal magnetization at the excitation pulse. Since pseudo steady state (PSS) of signals fluctuates over the first several TRs due to the half Fourier acquisition and restore pulses, saturation recovery (SR) preparation is performed once prior to measurement to reach the PSS quickly (Fig. 1a). T1-optimized imaging parameters (TR, T_{TD}, $\beta_{L,x}$,) are determined using Bloch simulations for the proposed method. Relaxation parameters for the simulation are: T1/T2=950/100 ms for gray matter (GM) and T1/T2=600/80ms for white matter (WM). Image comparison was performed on 1.5T(Avanto, Siemens Medical Solutions) using conventional acquisition (1) and proposed method. The common imaging parameters were: TR=750ms,TE=15ms, T_{ES}=3ms, ETL=113, FOV=230x230mm^2, matrix=226x256, 2 averages, 176 partitions, resolution = 1.0x1.0x1.0mm^3, and imaging time = 8.5 min. The parameters specific to the proposed method were: T_{TD}=550 ms, $\beta_{L,x}$=90^0, and ETL=113 (reduced to 60 by half Fourier).

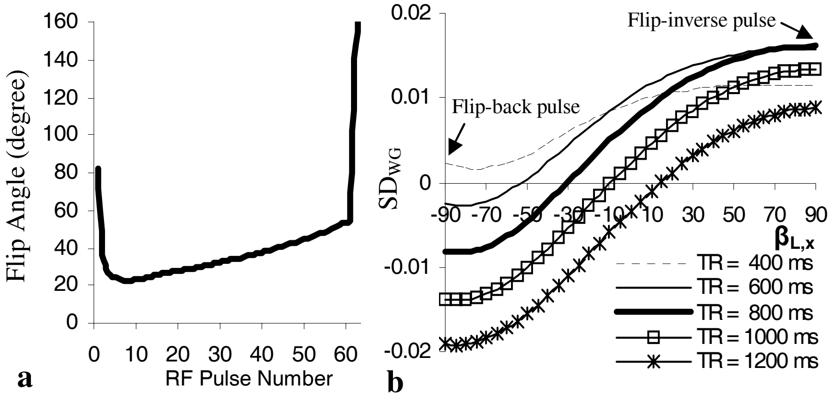

Fig. 2. Variable flip angle series of the proposed method (a) and signal difference between white and gray matters (SD_{wg}) at TE with a range of $\beta_{L,x}$ and TR

Results: Figure 2a represents the proposed variable flip angle series for the refocusing and the first two restore-pulses. Figure 2b shows the signal difference between WM and GM (SD_{wg}) at TE with a range of $\beta_{L,x}$ and TR from the simulations. T1 contrast is maximal at TR~800ms as $\beta_{L,x}$ is 90^0 (flip-inverse pulse) that rotates transverse magnetization to negative z axis. Figure 3 compares the two images generated using conventional full acquisition (Fig. 3a) (1) and proposed method with the optimal imaging parameters (Fig. 3b). The conventional acquisition (Fig. 3a) results in image blurring as well as signal recovery of GM due to the development of T2-weighted signal along the echo train. Therefore, T1 contrast between GM and WM is decreased. The proposed method (Fig. 3b) demonstrates enhanced image sharpness and T1 contrast.

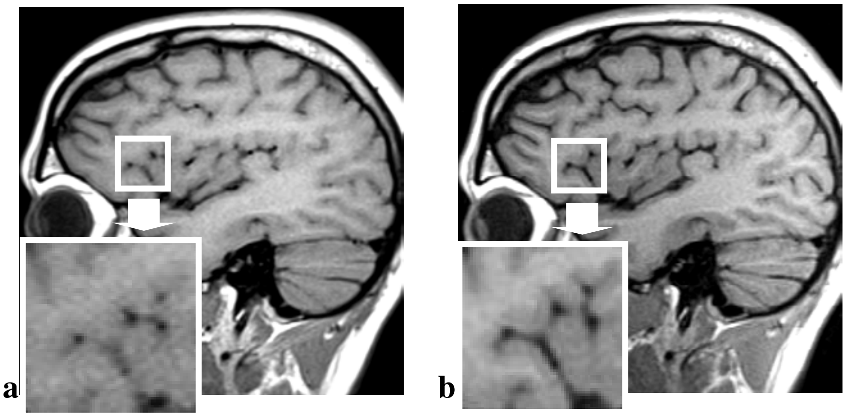

Fig. 3. Comparison of the images generated using conventional full acquisition (a) and proposed method (b). Note the increased sharpness and T1 contrast in (b) as compared to (a).

Conclusion: The proposed T1-optimized single-slab 3D turbo SE imaging method makes it feasible to use a long echo train without compromising contrast and spatial resolution. The half Fourier acquisition improves image sharpness and T1 contrast by reducing actual echo train length. The flip-inverse restore pulse contributes to T1 contrast by increasing the signal difference between WM and GM at TE. The SR pulse reduces signal fluctuation in k-space. Employing low flip angle series reduces energy deposition and maintains high signal-to-noise ratio even with a long echo train. This technique enables T1-optimized 3D turbo SE imaging in a wide range of applications within reasonable imaging time.

References: 1. J.P Mugler et al., Radiology, 216:891-899,2000
2. J.P Mugler et al., Proc ISMRM (1999), 1631