Simultaneous Acquisition of High-Resolution T_2-Weighted and Cerebro-Spinal-Fluid-Suppressed Images using Phase-Sensitive Dual-Acquisition Single-Slab Three-Dimensional Turbo Spin Echo Sequence

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Introduction: Small brain lesions such as multiple sclerosis (MS) are the most frequent inflammatory demyelinting disease of the central nervous system. T_2-weighted imaging is a gold standard for diagnosing infratentorial brain lesions, while fluid-attenuated-inversion-recovery (FLAIR) imaging is known to be highly sensitive to lesions close to cerebro-spinal-fluid (CSF) but less sensitive in posterior fossa (1). Additionally, high-resolution three-dimensional (3D) imaging is preferred due to the small size of lesions. Given the facts above, the purpose of this work was to develop a novel phase-sensitive dual-acquisition single-slab 3D turbo/fast spin echo (SE) pulse sequence for acquiring both T_2-weighted and CSF-suppressed images simultaneously in a single measurement.

Sequence Design and Reconstruction: A schematic of the proposed pulse sequence is shown in Fig. 1a, wherein the first acquisition generates in-phase images between CSF and other brain tissues while the second one produces out-of-phase images. The first acquisition consists of short non-selective excitation followed by a non-selective refocusing pulse train with variable flip angles (Fig. 2a), calculated based on prescribed signal evolutions that consider tissue-specific T_1 and T_2 values (2), to permit a long echo train and thus reduce imaging time. At the end of the long refocusing pulse train, transverse magnetization of CSF remains substantial due to its long T_2-relaxation value while that of other brain tissues is negligible. The remaining transverse magnetization is transferred to the negative longitudinal axis by a flip-down restore pulse (3). During a short period (TD_{short}), the longitudinal magnetization of other brain tissues rises rapidly to a positive value, while that of CSF remain at a negative value. Due to the anti-parallel alignment of the longitudinal magnetizations between CSF and other brain tissues, the second acquisition causes the echo of the former to be generated on the opposite side of the transverse plane to that of the latter. A long delay time (TD_{long}) is then inserted to ensure desired T_2-weighted contrast in the first acquisition. To reduce CSF-flow-related artifacts, balanced gradients were applied along the readout direction to compensate for the first-order moment at the center of each radio-frequency (RF) pulse (Fig. 1b), and matching crushers on either side of each refocusing pulse were shifted to the slab-axis for suppression of free-induction-decay (FID) artifact as compared to (3). The two images resulting from the proposed method were described as: $I_1 = I_{CSF} + I_b$ [1], $I_2 = -w_{csf} I_{CSF} + w_b I_b$ [2], where I_1, I_2 are the images from the first and second acquisitions, respectively, b is the non-CSF brain tissue, and w is the relaxation-induced amplitude-modulation factor in the second acquisition. CSF-suppressed image was reconstructed using: $I_{CSF-Suppressed} = (w_{CSF} I_1 + I_2) / w_{CSF}$ [3]. w_{CSF} was caculated by simulating the Bloch-equation.

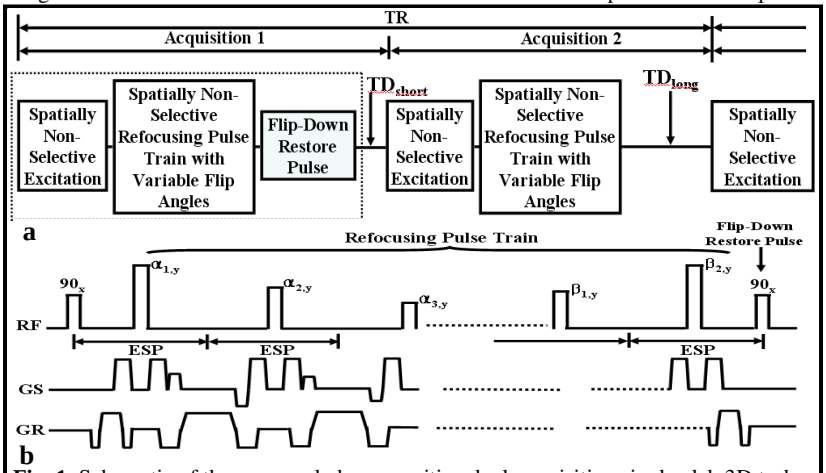

Fig. 1. Schematic of the proposed phase-sensitive dual-acquisition single-slab 3D turbo /fast spin echo (A) and timing diagram of the pulse sequence at each acquisition (B).

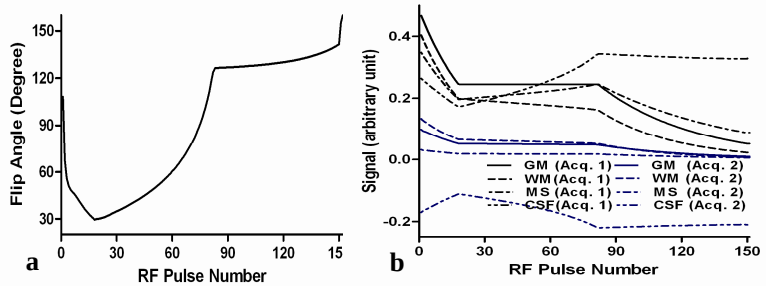

Fig. 2. Variable refocusing flip angles employed in the proposed pulse sequence (a) and signal evolutions of brain tissues (b). Note that only CSF signals are 180° out-of-phase between acquisitions while others are in-phase.

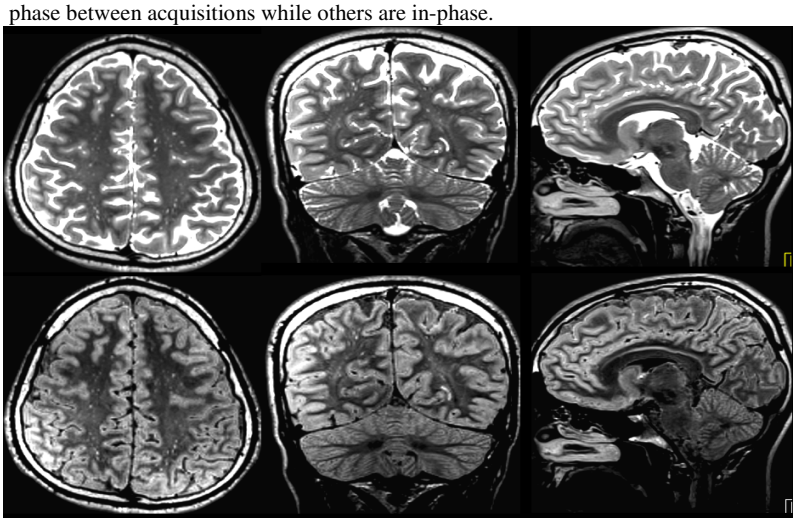

Fig. 3. Moderately T2-weighted (upper row) and CSF-suppressed (lower row) images acquired using the proposed dual-acquisition single-slab 3D turbo/fast SE in a single measurement. 3D images were then reformatted in the three orthogonal orientations

Materials and Methods: The Bloch-equation was numerically simulated to calculate signal evolution along the echo train in the proposed pulse sequence for CSF (T_1/T_2,4200/2200), gray matter (GM,T_1/T_2,950/100), white matter (WM,T_1/T_2,600/80), and MS (T_1/T_2,1300/150) using the following imaging parameters: TR/TE_{eff}, 3500/222ms; ETL, 150; ESP, 3.1ms; TD_{short}, 250ms; and TD_{long}, 2350ms. Imaging was then performed in five healthy volunteers at 3T (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany). Imaging parameters were: FOV, 230x230; matrix, 256x256, partitions, 176; and thickness, 1 mm; sagittal.

Results: The Bloch-equation simulation shows that the first acquisition yields T_2-weighted signal difference among the simulated tissues, while the second one generates much lower signal with GM, WM, and MS but slightly reduced sign-reversed signal with CSF (Fig. 2b). In volunteer studies, the proposed method successfully generated moderately T2-weighted/CSF-suppressed images simultaneously in single measurement (Fig. 3).

Discussion and Conclusion: We developed a novel phase-sensitive dual-acquisition single-slab 3D turbo/fast SE imaging method, demonstrating the feasibility of simultaneously acquiring T2-weighted/CSF-suppressed images although the CSF-suppressed image shows lower signal-to-noise ratio than the T2-weighted image due to the weighted averaging. This technique is expected to be very efficient for detecting small brain lesions such as MS.

References: 1.Gawne-Cain et.al,Neurology,1997;49:364,2.Mugler et.al,Proc ISMRM,2003;203,3.Park et.al.,MRM, 2007,58:982.