Dual-Echo Single-Slab 3D Turbo Spin Echo Imaging for Highly Efficient Sub-Millimeter Whole-Brain Gray Matter Imaging

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Introduction: Gray matter (GM) imaging, which provides valuable information in the studies of both physical and neuropsychological diseases, has been performed using conventional time-consuming double inversion recovery (DIR) pulse sequence (1), wherein long and short IR magnetization preparation is employed to selectively nullify both cerebro-spinal fluid (CSF) and white matter (WM) signals while retaining only GM signals. However, conventional DIR pulse sequence is practically limited due to the prohibitively prolonged imaging time, and is not suitable for high-resolution isotropic whole-brain GM imaging. Thus, the purpose of this work is to develop a highly efficient dual-echo single-slab 3D turbo/fast spin echo (DUESS-TSE) pulse sequence for sub-millimeter isotropic whole-brain GM imaging without long IR preparation.

Materials and Methods: A schematic of the proposed, DUESS-TSE pulse sequence for GM imaging is shown in Fig. 1, wherein 1) the first half of the echo train (ECHO-1) yields WM-suppressed images with short IR preparation, 2) the last half of the echo train (ECHO-2) generates CSF-dominant images, and 3) weighted image subtraction reconstructs sub-millimeter isotropic GM-only images without long IR preparation. In the long echo train, refocusing flip angles are sequentially varied with the following three steps (Fig. 2a) such that: 1) in an early portion of the echo train, prescribed GM-specific flat signal evolution is attained to reduce signal modulation of GM while achieving high SNR (2), 2) in a middle portion of the echo train, flip angles are linearly increased, establishing a pseudo steady state (PSS) for 180˚and thus preparing heavily T_2-weighted magnetization preparation, and 3) then, in the later portion of the echo train flip angle are decreased smoothly to another PSS for a relatively low flip angle, approximately equalizing CSF signals in ECHO-1 and ECHO-2. Sparse elliptical sampling in the k_y and k_z directions is employed in ECHO-1 and -2 in a pseudo-random fashion (3). Centric reordering (center in-out) is employed in ECHO-1 to maximize GM signals while inverse centric reordering (center out-in) in ECHO-2 to equalize CSF signals in both images. Additionally, saturation recovery preparation is inserted only once before actual imaging to avoid signal discontinuity around k-space center. Compressive sensing algorithm (4) is employed for the reconstruction of the data in both the ECHOes, generating WM-suppressed GM-CSF-dominant images in the first ECHO while only CSF-dominant images in the second ECHO, respectively. The two images are then weighted-averaged, yielding GM-only images. Numerical simulations of Bloch-equation were performed to investigate the signal evolutions of WM, GM, and CSF in each ECHO using the following imaging parameters: TR, 4000ms; echo train length (ETL) (ECHO-1), 90; ETL (ECHO-2), 90; ESP; 3.4ms; T_{MP}, 3500ms; TI, 570ms. Imaging was performed in two healthy volunteers on a 3T (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany) using the proposed DUESS-TSE pulse sequence. Imaging parameters were: FOV, 250x190mm^2 (sagittal); matrix size, 256x180; partitions, 160; thickness, 1mm; bandwidth, 750Hz/pix; imaging time; 8min.

Results: Figure 2 shows the refocusing flip angles in the proposed method (Fig. 2a) and the corresponding signal evolutions of WM, GM, and CSF along the echo train (Fig. 2b). For the flat signal evolution of GM in the first step of the refocusing pulse train, flip angles rapidly drop in the beginning of the echo train, and then exponentially increase. The linear increase and decrease of flip angles in the following refocusing pulses yields an approximately equal CSF signals at the k-space center in both the ECHOes, and thus preventing the weighting parameter in the weighted subtraction from being scaled. The resulting brain images in the proposed method are shown in Fig. 3. The first ECHO yields a WM-suppressed T_2-weighted image (Fig. 3a), while the second ECHO generates a CSF-dominant image (Fig, 3b), and a GM image (Fig. 3c) reconstructed from weighted averaging the two images in both the ECHOes. Figure 4 shows GM images reformatted to sagittal, coronal, and transversal orientations.

Discussion: A novel DUESS-TSE pulse sequence for sub-millimeter isotropic gray matter imaging without long IR preparation is proposed and successfully demonstrated. Since the proposed DUESS-TSE GM imaging does not employ the time-consuming long IR preparation while producing high quality of GM images in a clinically acceptable time, it is a promising alternative to conventional DIR and widens the applicability of GM imaging.

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References: 1.Pouwels,et al., Radiology, 2006, 241:873; 2. Park, et al., MRM, 2007, 58:982; 3. Busse, et al., MRM, 2008, 60:640; 4. Lustig, et al., MRM, 2007, 58: 1182.

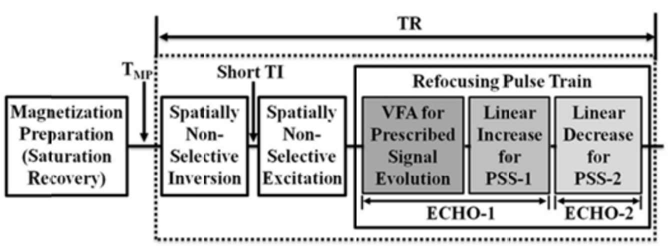

Fig. 1. A schematic of the proposed, dual-echo single-slab 3D turbo/ fast spin echo pulse sequence for GM imaging.

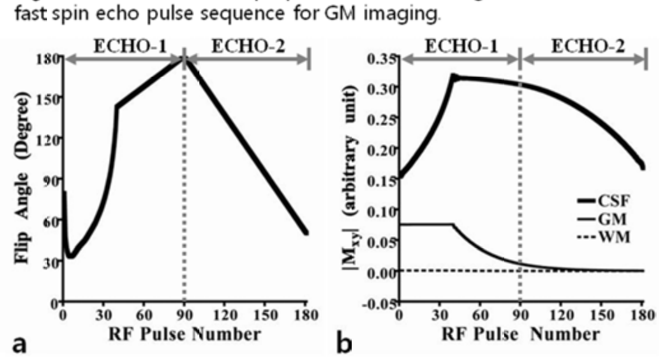

Fig. 2. Refocusing flip angles in each ECHO (a) and the corresponding signal evolutions of WM, GM, and CSF along the echo train (b).

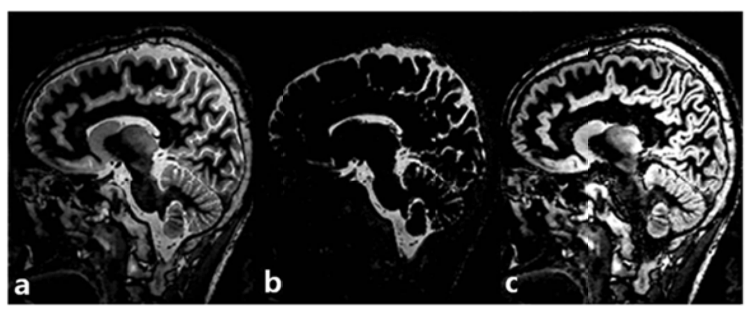

Fig. 3. Images acquired using the proposed method. WM-suppressed image in ECHO-1 (a), CSF-only image in ECHO-2 (b), and GM image (c) reconstructed from weighted averaging (a) and (b).

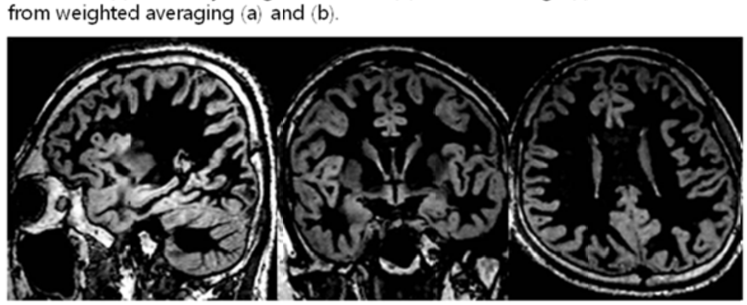

Fig. 4. Images reformatted in the sagittal, coronal, and transversal orientations.