Rapid Combo Acquisitions for Sub-millimeter Isotropic Fluid-Attenuated Inversion Recovery Imaging

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Introduction: Fluid-attenuated inversion recovery (FLAIR) imaging (1), which employs long inversion recovery (IR) magnetization preparation to selectively nullify cerebrospinal fluid (CSF) signals while retaining a clinically useful T2-weighted contrast, has been widely used for lesion detection in brain. However, since the long time of IR (~ 2000 ms) is required for CSF suppression due to its long T1-relaxation time (~ 4500 ms), imaging time in conventional FLAIR is prohibitively prolonged and spatial resolution is substantially limited. Hence, it is challenging to achieve high-resolution isotropic whole-brain fluid-attenuated imaging for detecting very small lesions in a clinically acceptable imaging time. To resolve this problem, in this work we develop a highly efficient rapid combo acquisition technique for sub-millimeter isotropic FLAIR, wherein instead of long IR preparation rapid gradient echo (PSIF) data (2) is acquired in the periphery of k-space while turbo/fast spin echo (TSE) (3) is encoded in the central region of k-space, simultaneously collecting both low (TSE) and high (PSIF) spatial frequency signals in the k_y and k_z directions and thus speeding up imaging time.

Pulse Sequence Design: A schematic and timing diagram of the proposed, rapid combo acquisitions for FLAIR (Combo-FLAIR) is shown in Figure 1. Unlike conventional FLAIR, in each time of repletion (TR) the proposed Combo-FLAIR pulse sequence consists of: 1) an IR radio-frequency pulse followed by a short time delay, 2) rapid gradient echo (PSIF) data acquisition in the peripheral region of k-space even during IR preparation, and 3) single-slab three-dimensional (3D) TSE data acquisition with variable refocusing flip angles in the central region of k-space. After a short time of delay with the IR pulse, rapid gradient echo (PSIF) data acquisition is selected, since it retains T1-relaxation induced signal recovery in the longitudinal direction during an IR period while generating T2-weighted contrast among brain tissues. Exploiting the fact that the slow recovery of CSF signals in the longitudinal direction is still retained during the PSIF data acquisition, Combo-FALIR is designed such that with CSF crossing its null point an excitation RF pulse in single-slab 3D TSE data acquisition is applied. To achieve a similar level of signal intensity in both PSIF and TSE acquisitions and thus eliminate potential signal discontinuity in k-space while employing long echo train and increasing imaging efficiency, single-slab 3D TSE employs variable refocusing flip angles (VFA), calculated using a two step (short exponential-flat) prescribed signal evolution (specific to white matter (WM)) along the echo train (3). Elliptical sampling in the k_y and k_z directions is employed, wherein low-spatial frequency signals are sampled in the TSE acquisition while high spatial frequency signals are collected in the PSIF acquisition. To minimize k-space signal discontinuity in both low and high spatial frequency regions, TSE and PSIF employ inverse centric reordering.

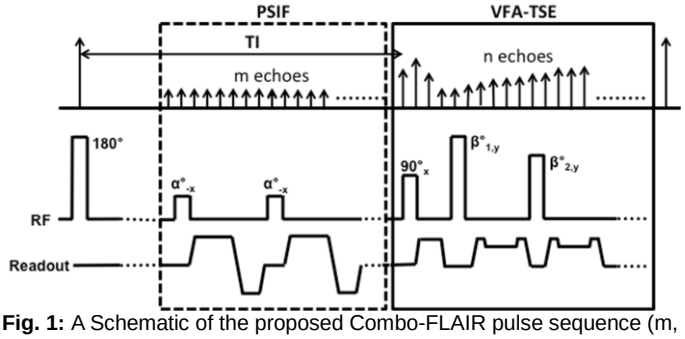

Fig. 1: A Schematic of the proposed Combo-FLAIR pulse sequence (m, 200; n, 181; α, 20 degree).

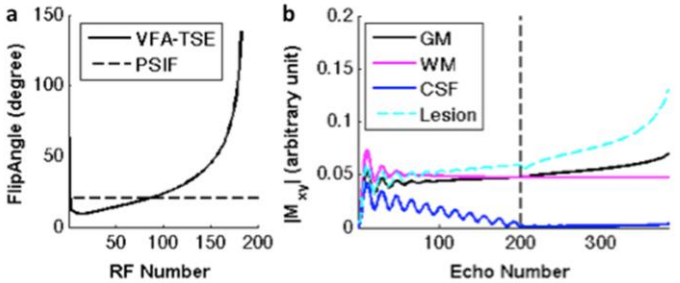

Fig. 2: (a) Flip angles in PSIF and VFA-TSE and **(b)** their corresponding signal evolutions in the proposed Combo-FALIR.

Materials and Methods: Numerical simulations of Bloch-equation were performed to investigate the signal evolutions of GM, WM, CSF, and lesion along the echo train in the proposed Combo-FLAIR using the parameters: T_1/T_2/PD of WM, GM, CSF and Lesion, 850/56/0.65, 1300/71/0.8, 4500/2200/1 and 1300/150/0.8, respectively. In-vivo imaging experiments were performed using conventional 3D FLAIR, conventional FLAIR with parallel imaging, and the proposed Combo-FLAIR. Imaging parameters common to the three imaging methods were: TR/TI, 7900/2300ms; ESP, 3.36ms, FOV, 250x190mm (sag); matrix size, 256x181; partitions, 160; thickness, 1mm. Those specific to conventional 3D FLAIR: TE_{eff}, 306ms; ETL, 181. Those specific to FLAIR with parallel imaging: TE_{eff}, 306ms; ETL per slice in turbo/fast SE, 181; GRAPPA reduction factor, 4. Those specific for the proposed method: TE_{eff}, 608ms; ETL in turbo/fast SE, 181; ETL/ESP/FA in PSIF, 200/5ms/20°.

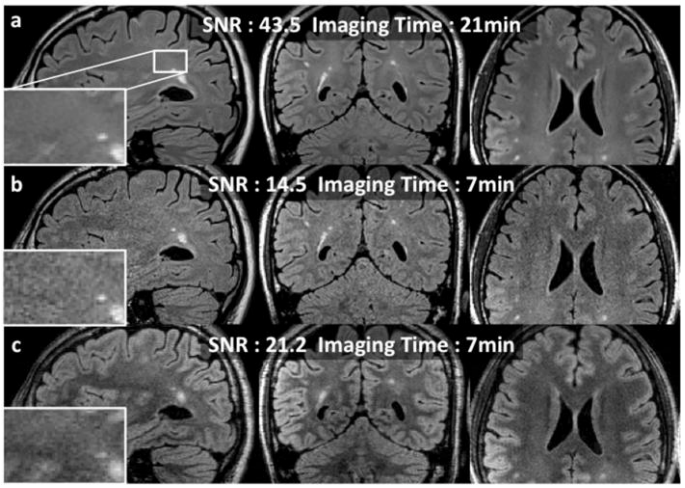

Fig. 3: Whole brain isotropic images with SNR and imaging time: the conventional FLAIR (a), the conventional FLAIR with GRAPPA (b) and the proposed Combo-FLAIR (c).

Results and Conclusion: In the proposed sequence, CSF signal is successfully suppressed with the inversion time of conventional FLAIR. Additional data acquisition with PSIF during the IR preparation is apparently preserving T_1 growing process with accelerating imaging speed about factor of 2 without any parallel imaging. As shown in Fig. 3, the proposed sequence generates heavily T_2-weighted and CSF-suppressed images with higher signal-to-noise ratio (SNR) compared with the conventional FLAIR with parallel imaging. In this work, we demonstrated the combo data acquisition during the magnetic preparation, especially inversion recovery, is successfully working with accelerating imaging speed without severely degrading image quality compared with parallel imaging.

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