Reliable Cortical Thickness Estimation with Reduction of Susceptibility-Induced Signal Loss using Optimized T1-Weighted Single-Slab 3D Turbo Spin Echo Pulse Sequence

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Introduction: In brain volumetry, magnetization-prepared rapid gradient recalled echo (MP-RAGE) imaging [1], which yields a strong T_1-weighted contrast among brain tissues and thus a highly accurate segmentation of the brain structures, has been widely used. However, since signals in MP-RAGE result from free induction decay (FID) without radio-frequency (RF) pulse induced refocusing, conventional MP-RAGE is sensitive to susceptibility-induced magnetic field inhomogeneities, yielding loss of signals or image distortions and thereby impairing the accuracy of cortical thickness measurement. As an alternative to conventional MP-RAGE, T_1-optimized, single-slab three-dimensional (3D) turbo/fast spin echo (SE) imaging [2], which employs a long refocusing pulse train with variable flip angles followed by a flip-down restore pulse train for contrast manipulation, is recently introduced and known to be resistant to local field variations. Thus, the purpose of this work is to investigate the feasibility of the proposed, single-slab 3D fast/turbo SE imaging for reliable, accurate estimation of cortical thickness, particularly for prefrontal and temporal lobes, which are the regions heavily affected by the susceptibility-induced field variations.

Materials and Methods: To compare signal evolutions of conventional MP-RAGE and the proposed pulse sequence in the presence of field inhomogeneities, numerical simulations of the Bloch-equation are performed. Brain imaging is performed in fifteen healthy volunteers at 3T whole-body MR scanner (MAGNETOM Trio, Siemens Medical Solutions, Erlangen, Germany) using conventional MP-RAGE and the proposed pulse sequence. Imaging parameters for MP-RAGE were: FOV=256x242 mm^2 (sagittal view); slice thickness=1mm; in-plane acquisition matrix size=256x242; partitions=160; TR=2300ms; TE=2.98ms; TI=900ms; flip angle=9°; and bandwidth=240Hz/pix. Those for the proposed pulse sequence were: TR=630ms; TE=10ms; echo spacing (ESP)=3ms; echo train length (ETL)=19; variable flip angles; and bandwidth=750Hz/pix. For postprocessing, Freesurfer v.4.0.5 (Massachusetts General Hospital, Harvard Medical School) is employed for cortical thickness measurement. All the procedures in the Freesurfer package, including skull stripping, image segmentation, and surface measurement, were automatically performed with the default parameters. Comparisons of cortical thickness in both the pulse sequences are statistically evaluated using one-way analysis of variance (ANOVA).

Results: Figure 1 shows that as compared to conventional MP-RAGE the proposed pulse sequence better retains the expected signal evolutions along the echo train with (dashed lines) and without (solid lines) magnetic field inhomogeneity (off-resonant frequency, 70 Hz). Figure 2 presents that the proposed pulse sequence (Fig. 2a) yields a T1-weighted contrast comparable to that in conventional MP-RAGE (Fig. 2c) while preserving signal intensity in the regions affected by susceptibility-induced field variations, particularly for the inferior prefrontal area (Figs. 2b and 2d). Figure 3 shows cortical thickness maps measured using conventional MP-RAGE (Fig. 3a) and the proposed pulse sequence (Fig. 3b). Cortical thickness in the proposed pulse sequence is in good agreement with that in [3], wherein gray matter (GM) cortices in the postcentral gyrus and occipital lobes are the thinnest while those in the temporal lobe and superior prefrontal lobe are thick. Furthermore, in the susceptibility-affected regions such as the inferior prefrontal area, cortical thickness in the proposed pulse sequence is over-estimated compared with that in MP-RAGE ($P<<0.05$).

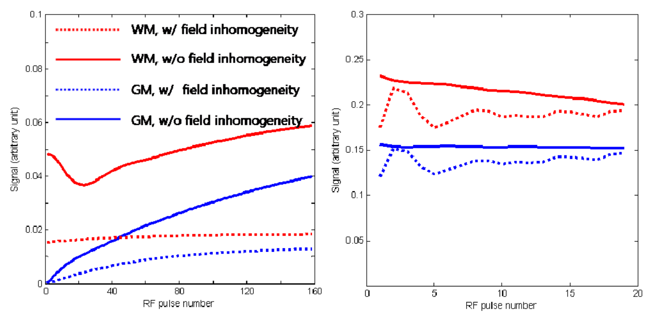

Figure1. Simulated signal evolutions along the echo train with and without field inhomogeneity (left: MP-RAGE and right: proposed pulse sequence).

Conclusion: We demonstrated the feasibility of reliable cortical thickness measurement in the whole-brain with reduction of susceptibility-induced signal loss using the proposed, T_1-optimized single-slab 3D turbo/fast SE imaging. Statistical evaluation shows that the proposed pulse sequence is resistant to susceptibility-induced field inhomogeneity and thus may have a potential for brain volumetry as an alternative to MP-RAGE.

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References: 1. Muggler 3rd, et al., JMRI, 1:561-567, 1991; 2. Park, et al., MRM, 58:982-992, 2007; 3. Fischl, et al., Proc. Natl. Acad. Sci. U.S.A. 97:11050-11055

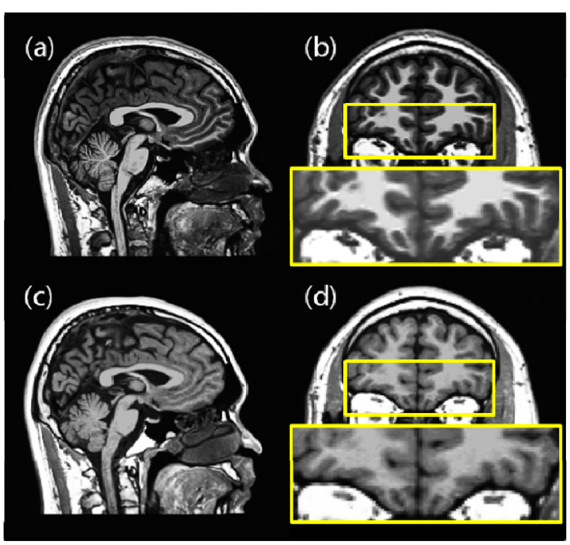

Figure2. Isotropic T1-weighted images: MP-RAGE (a) and (b), and the proposed pulse sequence (c) and (d).

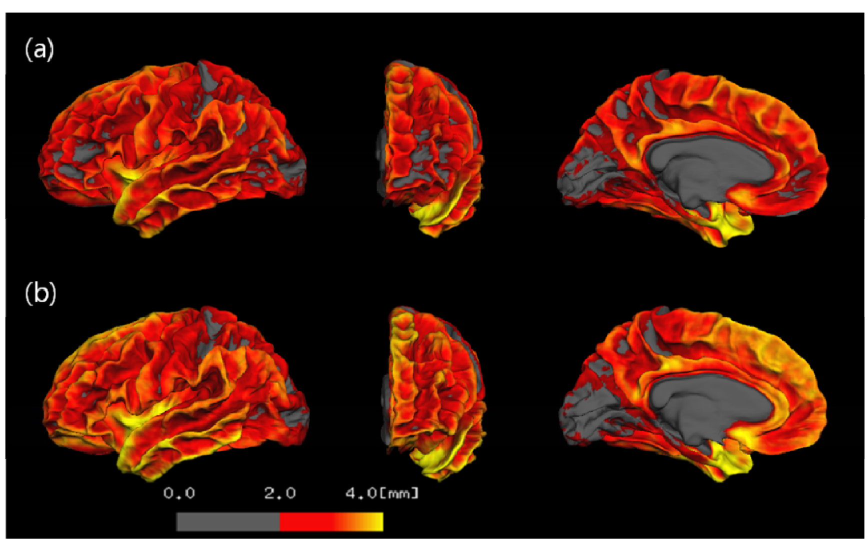

Figure3. Cortical thickness maps using MP-RAGE (a) and the proposed pulse sequence (b).