SNR-Optimized Accelerated Phase-Sensitive Dual-Acquisition Signle-Slab 3D Turbo Spin Echo Imaging

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Introduction: Phase-sensitive dual-acquisition single-slab 3D turbo/fast spin echo pulse sequence (PS-DATSE) (1), in which moderately T_2-weighted and cerebro-spinal fluid (CSF)-suppressed images are simultaneously acquired in a single measurement, was recently introduced as an efficient alternative to conventional time-consuming T_2-weighted and FLAIR imaging. Despite the imaging efficiency, it still suffers from noise amplification in the weighted-averaged CSF-suppressed reconstruction due to low signal intensity of CSF in the second acquisition (ACQ. 2) relative to that in the first acquisition (ACQ. 1). In this work, we develop an optimized PS-DATSE (OPS-DATSE), incorporating an optimal design of refocusing flip angle sweeping and an optimal reordering of k-space signals with elliptical incoherent under-sampling and thereby enhancing signal-to-noise ratio (SNR) and imaging efficiency.

Materials and Methods: A schematic of the proposed, OPS-DATSE pulse sequence is shown in Fig. 1, wherein an in-phase between CSF and other brain tissues is generated in ACQ. 1 while an opposed-phase image is produced in ACQ. 2. Refocusing flip angles along the long echo train (~180) in ACQ. 1 are calculated using a three-step prescribed signal evolution (exponential-flat-exponential) to acquire a moderately T_2-weighted image while those in ACQ. 2 are computed using a two-step transition of pseudo-steady-state (PSS) (30~120° PSS in the beginning of the echo train and 180° PSS afterwards) to increase CSF signals along the echo train (Fig. 2a). K-space signals in ACQ. 1 are fully acquired with pseudo-linear reordering (2) while those in ACQ. 2 (sparse CSF-only image) are sparsely (a half) sampled from the peripheral to central region (inverse centric reordering). In both the acquisitions, elliptical incoherent sampling is employed for compressive sensing reconstruction (3).The optimized refocusing flip angle schemes with the implemented reordering schemes approximately equalize the signal intensity of CSF at the central region of k-space over the two acquisitions, reducing noise amplification in the weighted averaging. Additionally, to avoid signal modulation around k-space center, which may result in low frequency artifacts in the reconstructed image, a saturation pulse is employed only once before actual imaging data acquisition. Numerical simulations of Bloch-equation were performed to investigate 1) signal evolutions of gray matter (GM), white matter (WM), and CSF in each acquisition, 2) CSF-signals along the echo train in ACQ. 2 with the proposed flip angle sweeping using the two-step transition of PSS, and 3) the effect of the saturation pulse on CSF-signals at the k-space center, using the following imaging parameters: TR/TE_{eff}, 3500/306ms; ETL (ACQ. 1), 180; ETL (ACQ. 2), 90; ESP, 3.3ms; TD_{Short}, 100ms; and T_{MP}, 1810ms. Imaging was performed in five healthy volunteers on a 3T (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany) using PS-DATSE and the proposed, OPS-DATSE. Imaging parameters were: FOV, 250x190mm^2 (sagittal); matrix size, 256x180; partitions, 160; thickness, 1mm. The total imaging time was 562sec for PS-DATSE and 436sec for OPS-DATSE. SNR comparison between PS-DATSE and OPS-DATSE was statistically evaluated using paired t-test.

Results and Conclusion: The Bloch-equation simulation shows that CSF signals at the k-space center for both the acquisitions are approximately equal with opposite signs (Fig. 2b). Fig. 2c indicates that the two-step PSS transition in ACQ. 2 effectively leads to comparable level of signals at the end of the echo train over a large range of the initial PSS flip angles, which is favorable to achieve high CSF signals with low energy deposition. The saturation pulse substantially reduces signal fluctuations over multiple TRs in the beginning of data acquisition (Fig. 2d), preventing ghosting artifacts in reconstruction. In conclusion, as shown in Fig. 3 and table 1, the proposed OPS-DATSE simultaneously enhances SNR and imaging efficiency while generating moderately T_2-weigthed and CSF-suppressed images.

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References: 1. Park, et al., MRM, 2010, 63:1422; 2. Busse, et al., MRM, 2008, 60:640; 3. Lustig, et al., MRM, 2007, 58:1182.

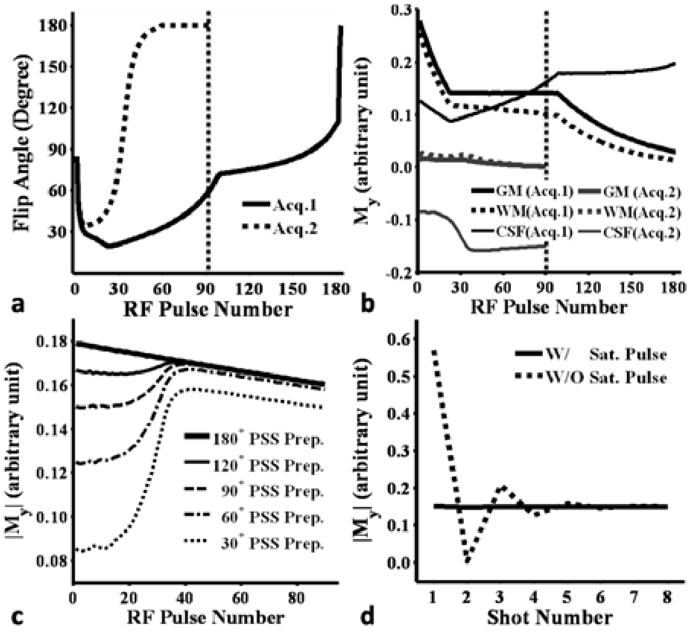

Fig. 2. a: Variable refocusing flip angles in each acquisition. **b**: The corresponding signal evolutions of brain tissues. **c**: Signal evolutions of CSF in ACQ. 2 with different flip angles for PSS preparation. **d**: K-space center signals of CSF in ACQ. 2 with and without the saturation pulse.

SNR_{GM}	T_2-weighted	CSF-suppressed
PS-DATSE	77.7 ± 6.3	46.4 ± 5.2
OPS-DATSE	80.4 ± 5.8	68.9 ± 4.6

Table 1. SNR comparison.

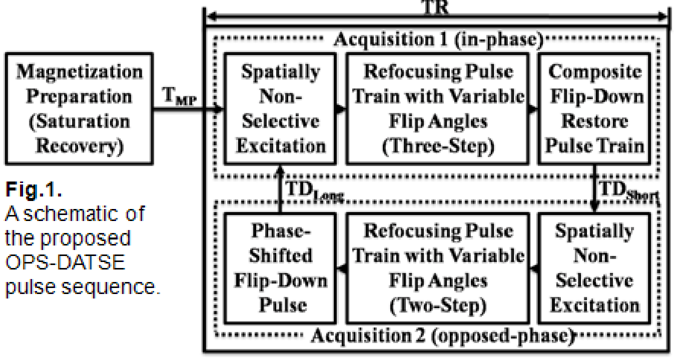

Fig.1. A schematic of the proposed OPS-DATSE pulse sequence.

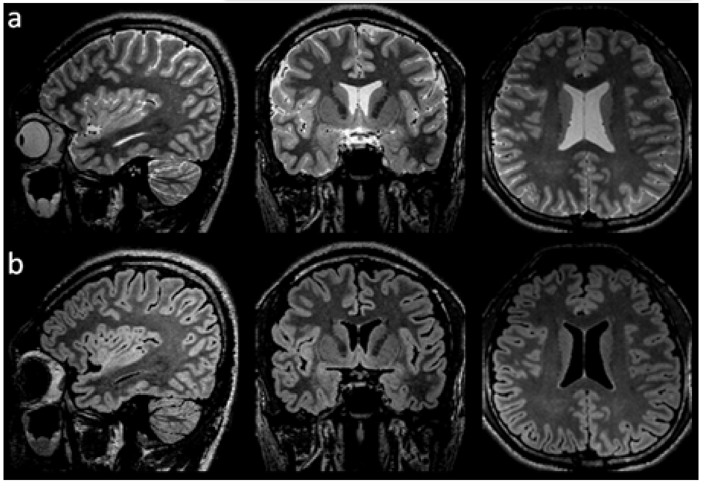

Fig. 3. Images acquired using the proposed OPS-DATSE. Moderately T_2-weigthed images in ACQ. 1 (a) and CSF-suppressed images in ACQ. 2 (b).