

Analysis of Magnetization Transfer Ratio Measurements at 3T Using Multiple-Acquisition Balanced SSFP

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Introduction. Magnetization transfer (MT) has become an important tool to study various tissue abnormalities, such as demyelination in brain white matter [1]. Recently, it has been shown that fast MT scans based on balanced steady-state free precession (bSSFP) with RF pulse modification achieve high SNR and high reproducibility at 1.5T [2]. At 3T, combination of multiple, phase-cycled, bSSFP scans might be required to overcome limitations from off-resonance artifacts. In this study, different recombination methods for the generation of accurate magnetization transfer ratio (MTR) maps were analyzed.

Methods. Simulations: BSSFP signal and corresponding MTR values (pu = percentage units) were simulated using a two-pool model [3], with quantitative MT parameters and T_{2f} values from [4], T_{2r} values from [5], and T_1 values from [6]. **Measurements:** All experiments were performed in 3D with sagittal orientation using a 144×192×192 matrix yielding 1.3 mm isotropic resolution. Slice-selective RF pulses with a flip angle of 30° were used with $T_{RF} = 2100 \mu s$ (TR = 4.83 ms) for the non-MT and $T_{RF} = 400 \mu s$ (TR = 3.13 ms) for the MT weighted bSSFP scan. Four images were acquired with different RF phase increments of -90°, 0°, 90°, and 180° with a total scan time of 5 min (using iPAT2 and partial Fourier 6/8). **Analyses:** Phase-cycled scans were combined using maximum-intensity (MI) bSSFP, sum-of-squares (SOS) bSSFP [7], and weighted-combination (WC) bSSFP with a weighting factor $p = 4$ [8]. Values in four different regions of interest (ROIs) were analyzed: WM_1 = corpus callosum splenium, WM_2 = frontal white matter, GM_1 = putamen, GM_2 = caudate nucleus (Fig. 3).

Results & Discussion. Simulations: Maximum MTR stability is expected for flip angles around 30° [2], yielding a broad bSSFP passband for both white matter (Fig. 1a,b) and gray matter (not shown). However, MTR values drop quickly outside a range of ± 20 Hz (Fig. 1c). Therefore, phase-cycled bSSFP scans were combined before MTR calculation. Resulting MTR profiles for the three combination methods are shown in Fig. 2. Maximum-intensity not only yields the flattest MTR profile and thus most effectively removes banding artifacts, but also results in only very slight decrease in MTR values. In contrast, SOS and WC bSSFP considerably lower resultant MTR values as compared to the on-resonant value. **Measurements:** Figure 3 shows brain MTR maps after combination of multiple-acquisition bSSFP. All investigated methods achieve a considerable reduction of off-resonance artifacts near the sinuses. A quantitative analysis in four ROIs is shown in Table 1. In region WM_1 , which is not affected by banding, MI bSSFP results come closest to the on-resonant value, while SOS and WC bSSFP yield slightly lower MTR values, as predicted by the simulations. In the other regions, which are affected by banding, MI and WC bSSFP achieve an enhancement of the reduced values observed in standard bSSFP. On the other hand, MTR values are not increased using SOS bSSFP. In summary, while SOS and WC recombination perform better than MI in terms of SNR, they falsify MTR values by summing all phase-cycled signals.

Conclusion. The quality of whole-brain MTR maps at 3T can be considerably increased using multi-acquisition bSSFP and MI projection removes off-resonance artifacts without significant MTR modification.

References. [1] Doustet et al., *Radiology* **182**:483-491 (1992); [2] Gloor et al., *MRM*, <http://dx.doi.org/10.1002/mrm.22694>; [3] Henkelman et al., *MRM* **29**:759-766; [4] Gloor et al., *MRM* **60**:691-700 (2008); [5] Stanisiz et al., *MRM* **54**:507-512 (2005); [6] Deoni, *JMRI* **26**:1106-1111 (2007); [7] Bangerter et al., *MRM* **51**:1038-1047 (2004); [8] Çukur et al., *MRM* **58**:1216-1223 (2007)

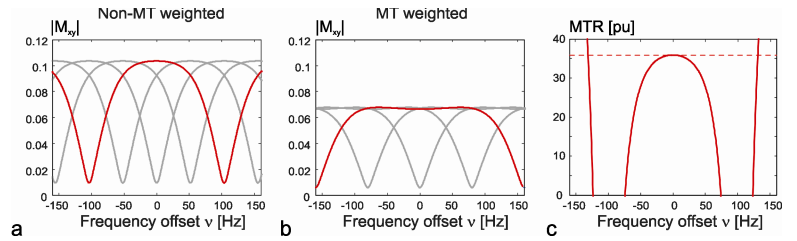


Fig. 1: Balanced SSFP off-resonance signal profiles for a sequence with RF flip angle of 30° and phase increments of 180° (red curves), -90°, 0°, and 90° (gray curves). (a-b) Simulations with a long RF pulse (non-MT weighted) and a short RF pulse (MT weighted) for white brain matter. (c) Off-resonance profile of resulting MTR (solid line) and on-resonant MTR value (dashed line).

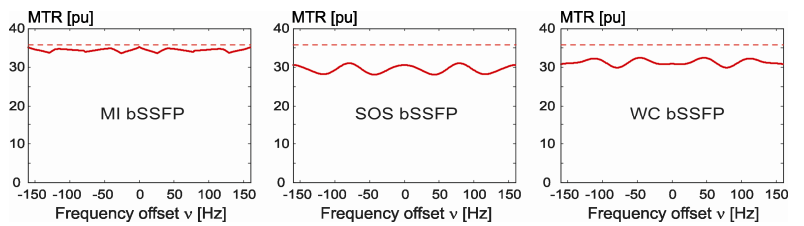


Fig. 2: Off-resonance frequency response of MTR (solid lines) after combination of four phase-cycled bSSFP acquisitions using three different methods for white matter. On-resonant MTR values are indicated by the dashed line.

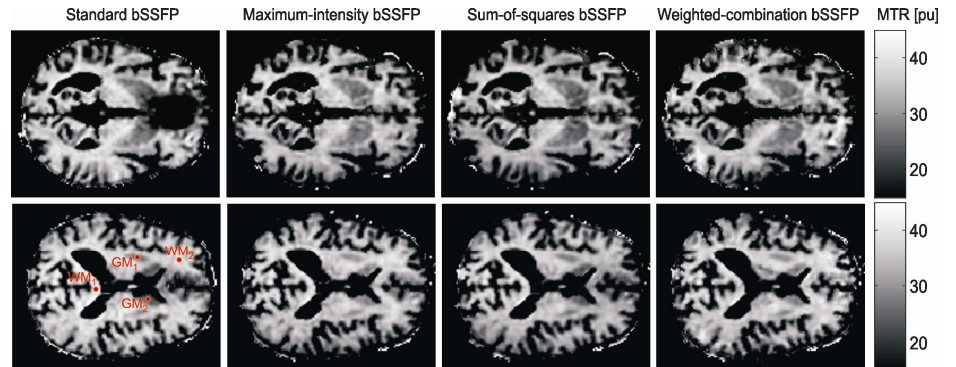


Fig. 3: Two slices of 3D brain MTR maps at 3T after combination of multiple-acquisition bSSFP using three different methods. While standard bSSFP-MTR values are drastically reduced in regions near the sinuses, recombination of phase-cycled bSSFP yields whole brain coverage.

	Standard	MI	SOS	WC
WM_1	40.6 ± 2.0	39.4 ± 1.6	38.5 ± 2.5	38.0 ± 2.0
WM_2	35.8 ± 3.6	37.3 ± 1.7	33.0 ± 2.1	37.6 ± 2.1
GM_1	28.1 ± 1.7	28.9 ± 1.6	27.6 ± 1.3	28.7 ± 1.3
GM_2	22.3 ± 2.3	28.2 ± 1.9	23.4 ± 2.0	27.9 ± 1.9

Table 1: MTR values (\pm standard deviation) in ROIs from different combinations of multiple-acquisition bSSFP. ROIs: WM_1 = corpus callosum splenium, WM_2 = frontal white matter, GM_1 = putamen, GM_2 = caudate nucleus (Fig. 3).