Simultaneous Fat Saturation and Magnetization Transfer Preparation with 2D Small-tip Fast Recovery Imaging

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Introduction: Small-Tip Fast Recovery imaging (STFR) is a steady-state imaging sequence that produces bSSFP-like images free of banding artifacts [1]. One advantage of STFR over bSSFP is its better compatibility with magnetization preparation, e.g., fat saturation, as the preparation can be done in every repetition without interrupting the steady state. A 3D tailored spectral-spatial (SPSP) pulse has been proposed to do fat sat for the 2D STFR sequence in presence of B_0/B_1 inhomogeneities [2]. This abstract describes an incidental magnetization transfer (MT) effect observed in phantoms and in-vivo experiments, which we believe can be desirable in clinical applications where both fat suppression and MT contrast are needed, e.g., cardiac imaging [3], cartilage imaging [3], breast imaging [3], and MR angiography [3]. We also demonstrate that STFR is much more sensitive to MT preparation than regular non-steady-state sequences. With simultaneous MT and fat sat preparation, STFR can efficiently produce high SNR MT contrast images that are free of artifacts caused by B_0/B_1 inhomogeneities. Moreover, MT contrast produced by the proposed sequence can be better controlled than bSSFP based MT imaging [4].

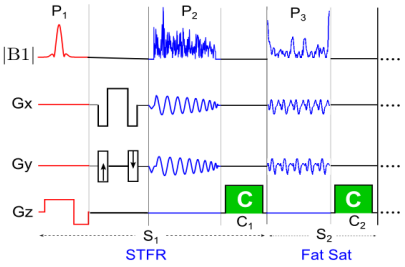

Fig. 1: 2D STFR with fat sat

Theory: Fig. 1 shows 2D STFR with fat sat, where the typical STFR sequence [1] containing slice-select tip-down pulse (P_1) and 2D tailored tip-up pulse (P_2) with gradient crusher (C_1) is followed by fat sat preparation (P_3 and C_2) that saturates and crushes fat [2]; a new RF spoiling scheme is applied to the sequence [2]. When P_3 is the proposed SPSP fat sat pulse, its integrated energy is typically 300~600 times of that of P_1 and P_2 combined, so any MT effect should be mainly caused by P_3. Note that P_3 can be regular spectral selective fat sat pulses if B_0/B_1 inhomogeneity is not a problem; P_3 can be any MT preparation pulses and C_2 may not be required if fat sat is not needed. Extending the STFR signal equation [1], the steady-state signal equation of water $M_t(r)$ in terms of the MT ratio (MTR), r, caused by P_3 can be described as $M_t(r) = M_0 \sin\alpha[rE_{1s}^2(1-E_{1f})\cos\alpha + (1+rE_{1s})(1-E_{1s})]/[1 - rE_{1s}^2(E_{2f}\sin^2\alpha - E_{1f}\cos^2\alpha)]$, where M_0 is the magnetization in equilibrium, α is the flip angle of P_1/P_2, $E_{1s} \triangleq e^{-T_s/T_1}$, $E_{1f} \triangleq e^{-T_f/T_1}$, $E_{2f} \triangleq e^{-T_f/T_2}$, T_s is the duration of each gradient spoiler, and T_f is the free precession time, i.e., the time from the peak of tip-down pulse to the beginning of P_2. r is 1 with an ideal fat sat pulse, but smaller than 1 when there is water excitation or MT effect. The set of curves shown in Fig. 2 are $M_t(r)/M_t(1)$ vs MTR for different T_1 and T_2 values (0.5 s $\leq T_1 \leq$ 2s, 50 ms $\leq T_2 \leq$ 200 ms), where the signal drops very rapidly as r is reduced from 1 to about 0.8, e.g., only 5% drop of r could cause 80% signal drop; this shows significantly high sensitivity of the sequence to magnetization preparation. So the proposed sequence can potentially produce the desired MT effect with a much smaller SAR requirement for the preparation pulse than conventional non-steady-state MT sequences.

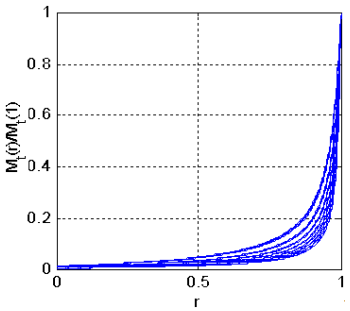

Fig. 2: Signal drop vs MTR

Methods and Results: We applied STFR with tailored SPSP fat sat in phantoms on a 3T GE scanner to demonstrate simultaneous fat sat and MT preparation. Three types of materials were put together in one FOV (see Fig. 3): mineral oil, water ($MnCl_2$ doped) and an MT phantom. The latter two materials have similar T_1 and T_2 as average brain tissue to rule out the potential T_2 effect in the experiment (different intensities of these two parts in the images are mainly due to different T_2^*) , and the MT phantom was designed to have similar MT effect to white matter [5]. The tailored tip-up pulse and a 2.7 ms tailored fat sat pulse were designed according to the B_0 map (-168~222 Hz, FOV = 18cm). 64*64 Cartesian sampled 2D data were acquired with spin-warp readout and the T_R was 16 ms. Fig. 3 shows the images acquired with fat sat on or off. When fat sat is turned on, the fat part is nulled, liquid water stays the same, and the MT phantom drops off by around 40% due to the MT effect.

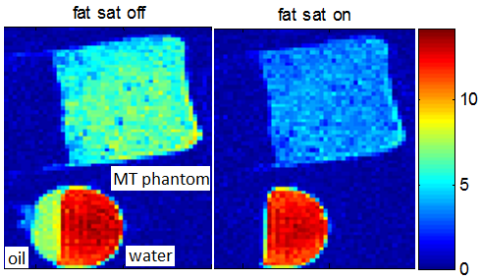

Fig. 3: The phantom experiment

We further tested the proposed sequence in an in-vivo experiment on the 3T GE scanner, where we scanned an axial brain slice of a healthy subject. Similar to the previous experiment, the tailored tip-up pulse and a 2.3 ms tailored fat sat pulse were designed based on the B_0 map (-25~54 Hz, 24 cm FOV), and 256*256 Cartesian data were acquired with the same imaging sequence with T_R = 19.1 ms. The images with or without fat sat are shown in Fig. 4, where we can clearly see the simultaneous fat sat (around skull) and MT effect (mainly in white matter).

Discussion and Conclusions: We demonstrated the high MT sensitivity of the proposed sequence in theory, which can significantly reduce SAR requirements compared to regular MT sequences. This fact may also be utilized for other types of magnetization preparation sequences, e.g., chemical exchange saturation transfer imaging [6]. Phantom and in-vivo experiments demonstrated that the proposed STFR sequence with tailored SPSP fat sat can potentially produce banding-free images with MT preparation and uniform fat suppression in the presence of B_0 inhomogeneities. The fat sat pulse can also be replaced by regular MT preparation pulse for MT only preparation. The proposed pulse is extendable to 3D imaging where parallel excitation will be required for good RF pulse performance over the entire volume [7] [8]. Moreover, with B_1 map incorporated into the design of P_2 and the tailored fat sat pulse, the proposed pulse can potentially address B_1 inhomogeneity problems which are typical in body imaging.

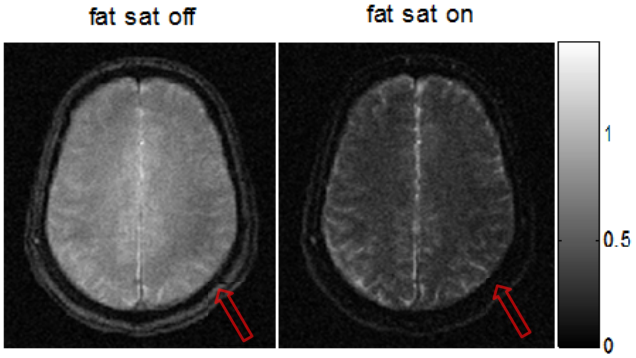

Fig. 4: The in-vivo experiment

References: [1] Nielsen et al., MRM 2012 April. [2] Zhao et al., Proc. ISMRM 21: ?. [3] Baudouin, Encyclopedia of MR 2007: 74-83. [4] Bieri et al., MRM 2007: 511-518. [5] Swanson et al., ISMRM 21: ?. [6] Van Zijl et al., MRM 2011: 927-948. [7] Sun et al., ISMRM 21: ?. [8] Zhao et al., Proc. ISMRM 20: 636.

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