Rapid steady-state imaging with T1 and T2 weighting using non-slice-selective tip-up pulses

Introduction: We introduce a new spoiled steady-state sequence that incorporates a non-slice-selective tailored RF pulse after each data readout segment. This "tip-up", or "fast recovery", pulse is designed to tip the spins in the desired imaging region back toward the longitudinal axis. Out-of-slice signal is removed using RF-spoiling (1). Under ideal conditions, the proposed sequence produces images that are similar to balanced SSFP, but without banding artifacts or transient fluctuations. We assess the feasibility of using this sequence for T2/T1-weighted brain imaging, using a short spiral tip-up pulse.

Theory: In the proposed "small-tip fast recovery" (STFR) sequence, a simple slice-selective tip-down pulse α is first played out, and the signal is acquired during a free precession interval of duration $\mathrm{T_{free}}$ and total precession angle $\theta(x, y) = \omega(x, y)\,\mathrm{T_{free}}$. After data readout, spins within the imaging slice are tipped back toward the longitudinal axis (mz) by a spatially-tailored tip-up pulse $\beta(x, y)$. Out-of-slice signal is removed using spoiling, i.e. by inserting a gradient spoiler S after the tip-up pulse, and cycling the RF phase using a linear phase increment of 117 times the TR number (1). Under the simplifying assumptions that both (i) RF pulse duration and (ii) the delay between the tip-up and tip-down pulses are negligible, the steady-state transverse STFR signal can be shown to be equivalent to the bSSFP on-resonance signal with flip angle 2α, in the short-TR limit.

Methods: One healthy volunteer was imaged at 3T in one 3D imaging session, and one 2D session. Off-resonance in the desired imaging slice was measured, and a tailored spiral tip-up pulse $\beta(x, y)$ of 2.3 msec duration was designed using $e^{i\theta(x,y)}$ as the target excitation pattern, and then traversing excitation k-space in reverse to obtain the final pulse. We used the small-tip design method in (2). In Session 1, a 3D image volume was acquired, in order to eliminate slice-profile distortions (24x24x3 cm^3 FOV). The flip angle was 8^o, the Ernst angle for gray matter. In Session 2, a 4 mm slice was acquired, to assess the practicability of rapid 2D STFR imaging using the theoretically optimal flip angles for bSSFP and STFR (32^o and 16^o, respectively). Since the exact gradient delays with respect to the RF waveform were not measured independently, several different gradient delays were applied for the spiral tip-up pulse.

Results: Figure 2(a) shows one slice from the 3D acquisitions. Most of the STFR image exhibits good gray/white matter tissue contrast (right). However, STFR fails to completely recover the signal near the frontal sinus, indicating that the B0 inhomogeneity is too large for this spiral tip-up pulse. Figure 2(b) shows 2D imaging results. Again, STFR produces good gray/white matter contrast and bright CSF, but is sensitive to gradient delays.

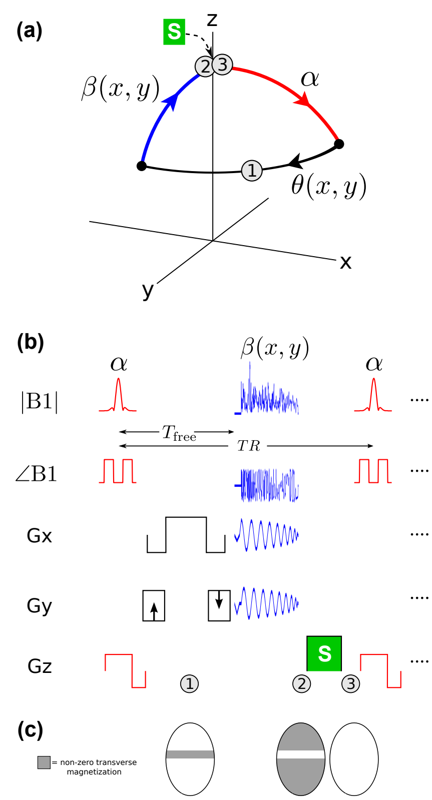

Figure 1: *Proposed STFR imaging principle. (a) Steady-state spin path. (b) Pulse sequence diagram, 2D imaging example. (c) Transverse magnetization at the time-points labeled 1, 2, and 3 in (a) and (b), for an axial slice.*

Discussion and Conclusion: Rapid and banding-free steady-state brain imaging with T2/T1 weighting is feasible using a standard head coil and a short tip-up pulse (~2 ms). The performance of the proposed method depends on the accuracy of the tip-up pulse, and in the future we expect STFR imaging to benefit significantly from parallel excitation hardware and high-order gradient shim systems. Further studies are needed to assess the performance of the proposed method in the presence of physiological variability and hardware non-idealities.

References: (1) Zur et al, MRM 1991; (2) Yip et al, MRM 2005.

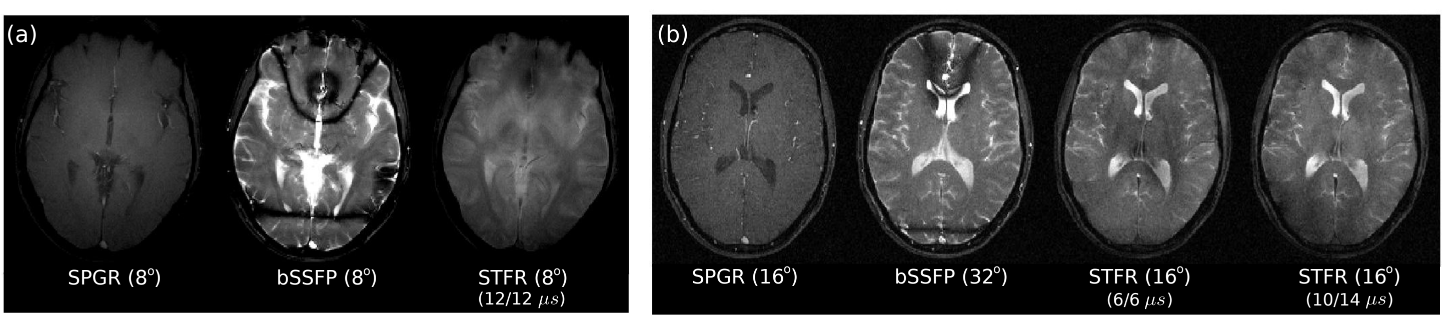

Figure 2: *(a) 3D and (b) 2D brain imaging results. In (a), the middle slice from each 3D image volume is shown. The applied x/y gradient time delays are indicated below the STFR images. [T_{free}/TR=7/11 msec; 256x192 in-plane matrix; acquisition bandwidth ±31.25 kHz]*