Steady-state imaging with 3D inner volume excitation

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Target audience: Researchers interested in RF pulse design, steady-state sequence, and inner volume imaging.

Purpose: Steady-state gradient echo sequences are generally not suitable for reduced field of view (rFOV) imaging using 3D tailored excitation pulses, due to the long duration of conventional 3D RF pulses. Recently, a method for joint RF pulse and continuous k-space trajectory design was proposed [1] that produces tailored RF pulses capable of exciting a non-smooth 3D pattern even with a single RF coil and short pulse duration (e.g., 4 ms). However, it is unknown whether this RF pulse is sufficiently accurate for rFOV steady-state imaging since even small residual flip angles outside the rFOV can lead to relatively large steady-state signal. In this work, we evaluate using the joint RF pulse design method in [1] for Inner Volume excitation (IVex) in three steady state sequences: RF-spoiled gradient echo (SPGR), balanced SSFP (bSSFP), and the recently proposed Small-Tip Fast Recovery (STFR) sequence [2,3]. In STFR, a "tip-up" RF pulse is played out after data readout, designed to restore magnetization to the longitudinal axis. STFR can produce similar tissue signal and contrast as bSSFP, however we hypothesized that the outer-volume signal for IVex-STFR and IVex-bSSFP may differ.

Method: We acquired in vivo brain data with conventional bSSFP and three IVex steady-state sequences (Table 1). Except for the conventional bSSFP sequence (acquired for reference), all sequences used a 4 ms 3D RF pulse designed to excite a 6x6x3 cm^3 inner volume. All sequences used the same 3DFT readout (192x192x42 matrix; 24x24x21 cm FOV). IVex-STFR, shown in Fig. 1, used a spectral pre-winding "tip-up" pulse [4] targeted to -30 to 30 Hz.

Sequence	Tip-down	Tip-up
Conv.-bSSFP	20 cm slab	N/A
IVex-SPGR	3D RF	N/A
IVex-bSSFP	3D RF	N/A
IVex-STFR	3D RF	Spectral

Table 1. Sequences in our experiment.

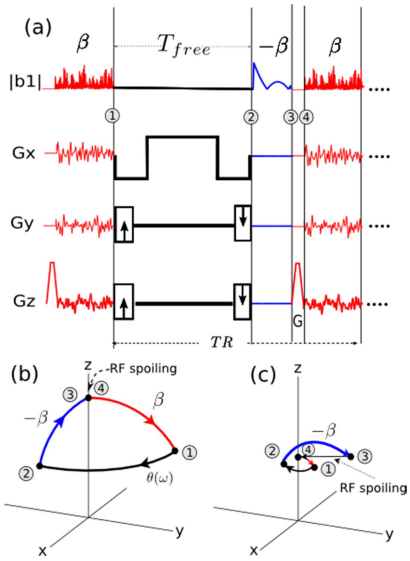

Figure 1*. Proposed "IVex-STFR" sequence with 3D selective tip-down pulse and spectral pre-winding tip-up pulse. (a) Pulse sequence timing diagram. (b-c) Spin paths for inner volume (IV) (b) and outer volume (OV) (c) regions. The IV region experiences both tip-down and tip-up pulses. The OV region mainly experiences the tip-up pulse. The use of RF spoiling will spoil and partially suppress the steady-state OV signal [2].*

Result: Figure 2 shows results for non-selective bSSFP, IVex-bSSFP, and IVex-STFR. Nine representative slices spanning the FOV in z are shown. The gray scale is normalized by the maximum image value of each acquisition. The inner volume in bSSFP and STFR shows similar tissue contrast, consistent with previous reports [2,3]. However the IVex-bSSFP images have undesired outer volume signal, especially near banding regions. This may be due to the fact that low flip angle bSSFP can have hyperintense signal near the banding edge even for low flip angles. The outer volume in IVex-STFR is effectively suppressed. We think there are two reasons for this: first, STFR does not have the hyperintense signal behavior near band edges [6]; second, the outer volume spins are partially suppressed by the tip-up pulse and RF spoiling (Fig. 1(c)). The IVex-SPGR image had high outer volume steady-state signal (not shown here to save space).

Conclusion and Discussion: Using the joint 3D selective excitation pulse from [1] and the RF-spoiled STFR sequence [2,3], we can achieve IVex steady-state imaging with good outer volume suppression. The outer-volume steady-state signal was considerably higher for SPGR and bSSFP, suggesting that 3D RF pulses with higher accuracy than that used here would be necessary for rFOV SPGR and bSSFP imaging. We expect IVex-STFR with a spatially tailored tip-up pulse to also show good outer volume signal suppression. With similar tissue contrast as bSSFP, STFR may be suitable for many potential rFOV applications, like high resolution functional MRI [5].

References: [1] Sun et al, ISMRM 2014 p1438; [2] Nielsen et al, MRM 2013; [3] Sun et al, MRM 2014; [4] Asslander et al, ISMRM 2013 p4249; [5] Sun et al, MRM 2014; [6] Sun et al, ISMRM 2014 p0029

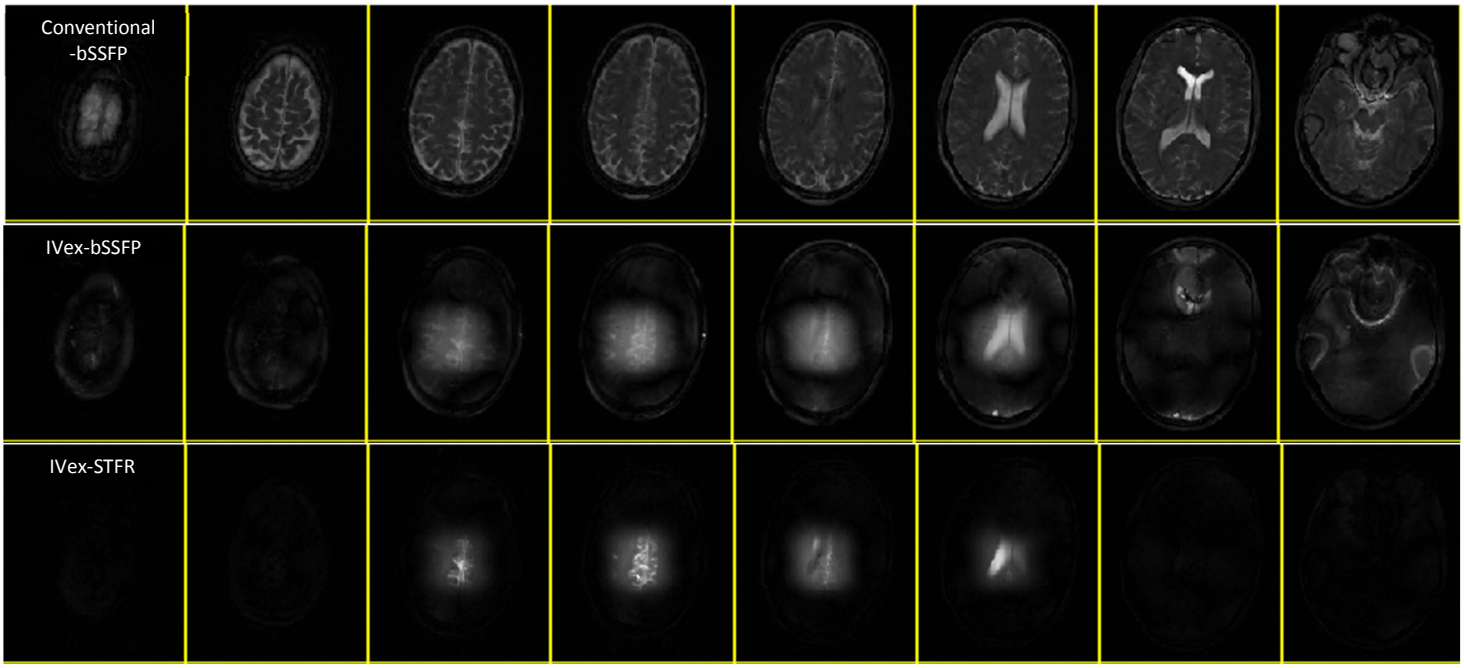

Figure 2*. Steady-state brain imaging without (top) and with (middle,bottom) inner volume excitation. (top) Conventional bSSFP; (middle) IVex-bSSFP; (bottom) IVex-STFR. As desired, all acquisitions show similar tissue contrast for inner volume spins. Mean relative outer volume signal was 0.42/0.25/0.08 for IVex-SPGR (not shown), IVex-bSSFP, and IVex-STFR, respectively.*