

# Acceleration of Spin-Locked 3D GRE Acquisitions for Rapid T1rho Mapping of the Brain

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**PURPOSE:** Quantitative T1ρ mapping of the brain has recently been demonstrated for a number of potential applications including Parkinson's disease [1-3], Alzheimer's disease [3,4], and stroke [5]. The technique may also prove useful for pH-sensitive imaging of psychiatric disorders [6]. 3D volumetric mapping is potentially critical for these applications to extend coverage, improve imaging efficiency, and enable motion correction. However, due in part to SAR limitations, saturation effects, and the need to acquire multiple spin-lock times (TSLs), 3D T1ρ mapping requires long acquisition times. This restricts the utility of the technique as well as the achievable spatial resolution. Recently, pulse sequence advances, in particular segmented spin-locked 3D GRE and FSE sequences [7,8], have greatly improved the acquisition speed of 3D T1ρ mapping. However, the potential to further speed up these acquisitions for brain imaging using methods to accelerate sampling of the k<sub>Y</sub>-k<sub>Z</sub> phase encoding plane such as 2D partial Fourier and 2D parallel imaging has not yet been rigorously evaluated. The purpose of this work is to evaluate a number of acceleration techniques to more rapidly generate 3D T1ρ maps of the brain using a 3D GRE approach. It is demonstrated that, compared to a fully-sampled reference, T1ρ mapping of the brain can be substantially accelerated while limiting errors in the resultant map.

**METHODS:** The head of a healthy subject (male, 29 yrs) was imaged using a fully-sampled segmented spin-locked 3D GRE sequence on a 3T Siemens Trio MR system after obtaining informed written consent. Images were acquired with a Siemens 12-channel matrix receive head coil with frequency S/I (X), phase R/L (Y), and slice A/P (Z). A coronal orientation was selected to take advantage of unique coil sensitivity profiles in both the R/L and A/P directions for parallel imaging. Parameters were: FOV=22×22×20cm<sup>3</sup>; matrix=128×128×40; resolution=1.7×1.7×5.0mm<sup>3</sup>; TSLs={10,25,40,55}ms; B<sub>1SL</sub>=400Hz; segment duration=1500ms; lines/segment=32; TR/TE=5.6/2.5ms; α=10°; BW=260Hz/px; and total scan time=16:08 (4:02 per TSL image). Complex raw data was reconstructed offline using Matlab. 2D acceleration was simulated by undersampling the k<sub>Y</sub>-k<sub>Z</sub> phase-encoding plane of the raw k-space data, reconstructing the accelerated data set for each TSL image, and generating the resultant T1ρ map using a mono-exponential decay model. Methods simulated included zero-filling, 2D partial Fourier sampling (75%), 2D SENSE (R<sub>Y</sub>×R<sub>Z</sub>=2×1, 2×2), and combinations of these techniques. Each method's undersampling parameters were varied over a broad range to assess different degrees of acceleration. For 2D SENSE, the TSL=10ms volume was used to estimate coil sensitivity profiles. The option of using only two TSLs (10 and 55ms) vs. all four was also considered. To reduce computational load, undersampling was only applied to three representative axial (Y-Z) slices. The accuracy of the undersampled T1ρ maps was determined by comparing them to the fully-sampled reference T1ρ map. Before comparison, the reference map was masked to include only values typical of brain matter (T1ρ=50-100ms), and this mask was then applied to the undersampled maps. Normalized root mean square error (ε) was calculated to determine the percent error of the undersampled T1ρ values (excluding zeroed voxels). The increase in average voxel standard deviation (σ) needed to produce an equivalent ε was estimated by applying normally-distributed (μ=0; σ) additive noise to the reference T1ρ map and iteratively calculating ε(σ). Note that this average σ ignores spatially-dependent noise amplification and does not account for the noise in the reference T1ρ map.

**Table 1: Method Performance**

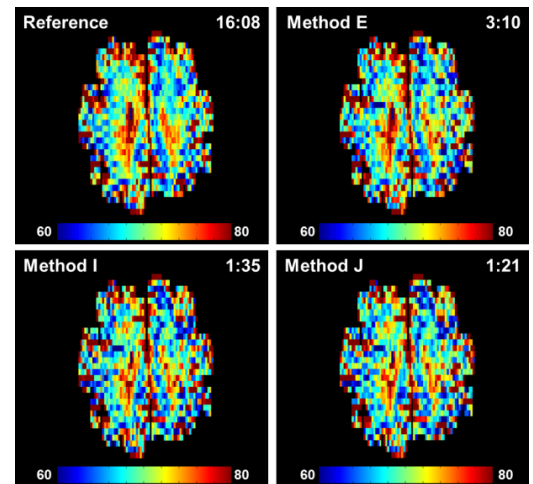
Method	R	ε (%)	σ
A: Cut Corners	1.3	3.9	1.9
B: Partial Fourier	1.3	3.1	1.5
C: 2×1 SENSE	2.0	2.8	1.3
D: 2×2 SENSE	4.0	5.5	2.8
E: B + D	5.1	5.7	2.8
F: A + B + D	6.0	6.0	3.1
G: 2 TSLs	2.0	5.1	2.7
H: 2 TSLs + C	4.0	5.2	2.7
I: 2 TSLs + E	10.2	5.0	2.6
J: 2 TSLs + F	12.0	5.5	3.0

**RESULTS:** Table 1 lists the performance of a number of undersampling methods (A-J) with various reduction factors R. The reported values are the averages for the three individually-evaluated slices. 2D SENSE acceleration performed well up to R=4 (C,D). Combinations of techniques yielded R=5 (E) and R=6 (F). The error in (E) increased only slightly compared to (D). Use of only two TSLs, which effectively doubles R, did not increase ε in cases of high acceleration (I,J). Figure 1 compares a reference T1ρ map axial slice to those generated by methods (E), (I), and (J). Despite large reductions in the number of samples acquired, the accelerated maps show similar T1ρ contrast as the reference.

**DISCUSSION:** Reduction of acquisition time will make 3D T1ρ mapping of the brain more useful, cheaper, and less sensitive to motion. However, amplification of noise as a result of undersampling will require some number of additional studies to yield the same effect size as a single fully-sampled acquisition. This can be estimated from σ in Table 1. For example, Ref [3] shows hippocampal T1ρ values between Parkinson's and Alzheimer's patients and controls differing by ~5ms. By estimating the increased variance in the measurements from Table 1, an additional 5 subjects would be required using R=10.2 to yield the same effect size as a single-subject fully-sampled T1ρ map for this scenario. For many applications, and for general utility in existing protocols, this may be a favorable or even requisite tradeoff.

**CONCLUSION:** We have demonstrated that 3D T1ρ mapping acquisition times can be reduced by >10× while still providing substantial detectability of T1ρ contrast. This will improve the utility of 3D T1ρ mapping techniques and may enable new applications.

**REFERENCES:** [1] Michaeli S, *et al.* *Mov Disord* 2007; 22:334-340. [2] Nestrilas I, *et al.* *J Neurol* 2010; 257:964-968. [3] Haris M, *et al.* *J Neurol* 2011; 258:380-385. [4] Borthakur A, *et al.* *NeuroImage* 2008; 41: 1199-1205. [5] Jokivarsi KT, *et al.* *Stroke* 2010; 41:2335-2340. [6] Magnotta VA, *et al.* *PNAS* 2012; 109:8270-8273. [7] Li X, *et al.* *MRM* 2008; 59:298-307. [8] Chen W, *et al.* *ISMRM* 2012; 3419.



**Figure 1:** Fully-sampled reference and undersampled axial (Y-Z) T1ρ maps generated using the methods indicated (see Table 1). The total acquisition time that would be required for each is shown in min:sec. T1ρ map units are in msec.