Reproducibility of T1 and tissue fractional volume mapping using FRASIER: an application to fMRI settings

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Introduction

Automated segmentation of the brain structure in MR images has been widely utilized in quantitative tissue volumetric measurement. MR images weighted by spin-lattice relaxation time constant (T_1) are usually employed for tissue segmentation. However, the signal intensity of a T_1-weighted image is sensitive to hardware settings such as RF coil uniformity and gradient-induced eddy currents [1]. Furthermore, the segmentation algorithms used for T_1-weighted images usually rely on statistical models for a general population, but may not account for individual variation. Recently, we proposed a new brain segmentation method using quantitative T_1, named FRASIER [2]. Information on tissue fractions in each voxel can be incorporated into functional MRI (fMRI) studies for improving data interpretation. At a spatial resolution typically used in fMRI (3-4 mm), FRASIER can obtain T_1 and fractional volume (f_v) maps in every 10 seconds. In this study, we test the reproducibility of T_1 and f_v mapping, and demonstrate the application of FRASIER in fMRI settings.

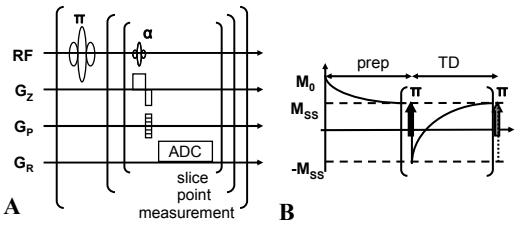

Fig 1. A sequence diagram of a single-shot IR LL-EPI SS (A) and acquisition paradigm (B). When the signal approaches a steady state during preparation (prep.), a time-series of single-shot EPI acquisition is repeated over slices following IR pulse during the time of duration (TD). This process is repeated across measurement.

Methods

FRActional Signal mapping from InvErsion Recovery (FRASIER): FRASIER is based on a recently developed fast T_1 mapping method using inversion recovery Look-Locker echo-planar-imaging at a steady state (IR LL-EPI SS) [3]. Using a single-shot IR LL-EPI SS, the effective relaxation time constant (T_1^*) can be expressed as $1/T_1^*=1/T_1-\ln(\cos\alpha)/TR$, where α is a flip angle, and TR is a time gap between two consecutive EPI acquisitions of the same slice. The signal recovery during the time of duration (TD, see Fig.1) is described as $S(t) = M_{SS}|1-2\exp(-t/T_1^*)|$. The measured voxel-wise signal during IR procedure is fitted into a three-compartment (WM, GM, and CSF) exponential recovery model: $signal = \sum fs_i \times (1-2\exp(t/T_{1,i}^*)$, where subscript i represents each tissue. f_v can be derived from the measured fractional signal (f_s) by considering the each tissue density and the steady state signal [2]. Note that T_1^* and T_1 in WM, GM, and CSF need to be determined prior to fitting. Considering individual variations in T_1, T_1 and T_1^* in WM and GM are obtained individually from the whole brain T_1 histogram and T_1 value in CSF was set to 4500 ms.

MR imaging: Nine healthy subjects were scanned using a single-shot IR LL-EPI SS sequence. The following MR imaging protocols were used: non-selective IR, TR/TE=400/13 ms, α=16°, matrix=64x64, bandwidth=4112Hz/voxel, 15 slices, no gap between slices, and TD=10s (Fig.1B). A series of five IR LL-EPI SS measurements were acquired in 1 min including the preparation (prep.) time of 10 s. After 20 min of fMRI experiments, another series of five IR LL-EPI SS scans were repeated to test the reproducibility of T_1 and f_v mapping using FRASIER. For convenience, we referred to the first scan series as "Test", and the latter one as "Re-test" in the following content.

Data analysis: A total of 10 T_1 and f_v maps were acquired for each subject (5 in Test and 5 in Re-test). Registration parameters were obtained by registering each IR LL-EPI SS image to the average IR LL-EPI SS images over 10 measurements and then were applied to the fitted T_1 and f_v maps to correct for head motion. Voxel-wise standard deviation (SD) of T_1 and of $f_{v,GM}$ were calculated to test reproducibility of FRASIER among the i) Test scan (within the first 5 measurements), ii) Re-test scan (within the last 5), and iii) Test and Re-test scans (all 10)

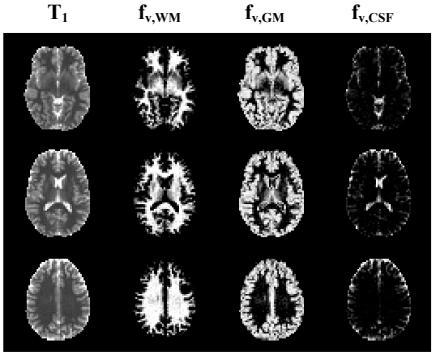

Fig 2. Representative 3 slices of T_1 and f_v maps are shown. T_1 maps are presented from 0 (black) ms to 3500 (white) ms, and f_v maps are shown from 0 to 1.

Results and Discussion

FRASIER was incorporated into an fMRI protocol, taking 1 min each before and after the fMRI experiment. Ten T_1 and f_v maps were reliably obtained from the FRASIER measurements (5 before and 5 after the fMRI scan). Figure 2 demonstrates the representative 3 slices of T_1 and f_v maps in WM, GM and CSF (from 15 slices). Over five consecutive measurements, voxel-wise average SD of T_1 and $f_{v,GM}$ were 37 ms and 3.5% in Test and 40 ms and 3.7% in Re-test. Reproducibility considering both Test and Re-test was reduced (59 ms and 5.6%), as shown in Tab 1 and Fig 3., probably due to the head motion between the two FRASIER runs separated by 20 min. Note that each of the T_1 and $f_{v,GM}$ maps were measured within 10 seconds. When applying 1 min FRASIER, averaging over 5 measurements improves the signal-to-noise ratio by a factor of 2.2 times, the voxel-wise SDs of T_1 and $f_{v,GM}$ would be improved to approximately 18 ms and 1.7 %

This work demonstrates that FRASIER can be used to measure T_1 and f_v in the brain within 10 seconds with high reproducibility. When FRASIER sequence is incorporated into an fMRI protocol, it provides T_1 and f_v maps with similar geometric distortion as fMRI images (e.g. BOLD) because the gradient-echo EPI kernel with the same configuring parameters as fMRI acquisition were used in FRASIER sequence. Therefore, additional image registration between fMRI and fv maps is not required, while most of automated brain tissue segmentation need normalization and smoothing due to the dependence of *a prior* image template. This advantage would allow the proposed method to be easily used in patient populations with severe neurological disorders and age-dependent populations.

	SD of T_1 (ms)	SD of $f_{v,GM}$ (%)
Test	37±8	3.5±0.3
Re-test	40±9	3.7±0.5
Test & Re-test	59±9	5.6±1.2

Tab 1. Voxel-wise average SDs of T_1 and $f_{v,GM}$ over 9 subjects

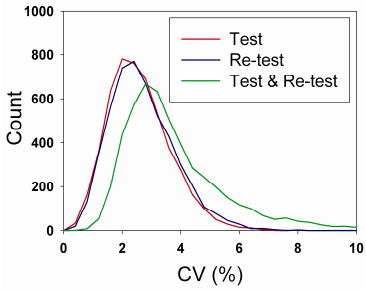

Fig 3. The representative coefficient of variation (CV) histogram of T_1.

Acknowledgements

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Reference

1. Sled et al, IEEE,1998;17(1):87-97. 2. Shin et al., ISMRM, 2009.
3. Shin et al., MRM, 2009;61(4):899-906.