Brain Tissue Segmentation using Fast T1 Mapping

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Introduction

Automated segmentation of the brain structure in MR images has been widely utilized in quantitative tissue volumetric measurement, such as voxel-based morphometric (VBM). White matter (WM), gray matter (GM) and cerebral spinal fluid (CSF) are commonly used as representative components of brain tissue compartmental models. 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, as well as susceptibility artifacts due to subject's anatomy [1]. Furthermore, the segmentation used for T_1-weighted images relies on statistical models for a general population, but may not consider for variations in age-dependent groups or specific patient populations. In this study, we present an automated brain tissue segmentation method based on modeling of individual quantitative T_1 values. This method is insensitive to instrumental settings and can be used to address specific populations.

Methods

Fast T_1 measurement: Recently a fast T_1 measurement method using inversion recovery Look-Locker echo-planar imaging at a steady state (IR LL-EPI SS) was proposed [2]. When a series of α ° pulses with a time interval of TR are applied after an inversion pulse, the effective relaxation time constant (T_1^*) can be expressed as $1/T_1^*=1/T_1-\ln(\cos\alpha)/TR$. As shown in Fig.1, after the signal intensity approaches to a steady state (M_{SS}), segmented LL-EPI acquisitions are performed, each with duration of TD. With no delay time between the LL-EPI acquisitions, the signal intensity is described as $S(t) = M_{SS}|1-2\exp(-t/T_1^*)|$. .

Automated segmentation: A three-compartment model (WM, GM, and CSF) was used for segmentation. Tissue segmentation was defined as fractional volume (f_v) measurement. The signal normalized by M_{SS} can be expressed as:

$$signal = \sum_{i=WM,GM,CSF} \rho_i f v_i (1-\exp(-TR/T_{1,i}))/(1-\exp(-TR/T_{1,i})\cos\alpha)\times(1-2\exp(t/T_{1,i}^*)),$$

where subscript i represents each tissue type, and ρ is the water density (0.73, 0.89, and 1 in WM, GM, and CSF [3]). Considering individual variations in T_1 [4], T_1 and T_1^* values in WM and GM are measured individually from the whole brain T_1 histogram (see Fig 2), and T_1 value in CSF was set to 4500 ms.

MR imaging: Nine healthy subjects were scanned using the segmented IR LL-EPI SS sequence on a Siemens 3T scanner. The following MR imaging protocols were used: non-selective IR, TR/TE=400/13 ms, α=16°, matrix=128x128, bandwidth=1056Hz/voxel, 5 lines per acquisition, 35 slices, no gap between slices, TD=10s (Fig.1b), and total scanning time = 4 min and 32 s.

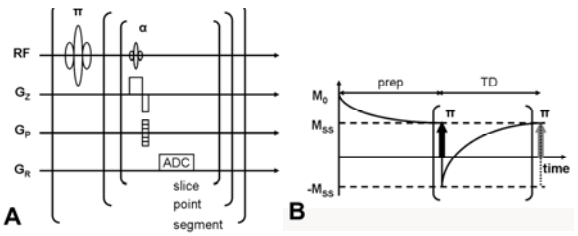

Fig 1. IR LL-EPI SS sequence diagram (A) and acquisition paradigm (B). After IR pulse, a series of α° excitation RF pulses are applied to acquire partial k-space data (ADC) following the LL acquisition algorithm. Before the first inversion pulse and data acquisition, a series of α° preparation pulses (prep) are applied for time of duration (TD).

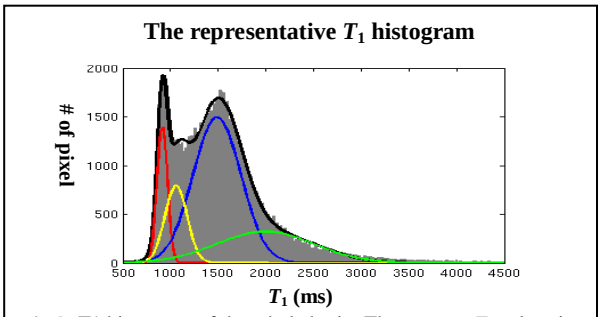

Fig 2. T1 histogram of the whole brain. The average T_1 values in WM and GM are calculated from two Gaussian distribution fittings (Red: WM, Blue: GM, Yellow: WM+GM, and Green: GM+CSF).

Results and Discussion

From the T_1 histograms, average T_1 values (N=9) were measured as 921 ± 28 ms in WM and 1537 ± 32ms in GM. Fast whole brain T_1 mapping was achieved by the IR LL-EPI SS method and f_v maps were obtained from the three-compartment model. Fig.3 shows the representative 3 slices of T_1 and f_v maps, and corresponding probability maps using statistical parametric mapping (SPM). In Fig.4, a voxel-by-voxel comparison of tissue segmentation between the proposed method and probability (prob.) map using SPM in whole brain is shown. The automated segmentation based on quantitative T_1 values is expected to have advantage over segmentation based on relative signal intensity in T_1-weighted image. The correction of the noninformality in the signal intensity is not needed in the current method. Quantitative T_1 maps provide larger range of contrast than T_1-weighted images, which may improve the accuracy of the segmentation. The proposed method can also be easily used to measure tissue fractions in disease populations and age-dependent groups.

References [1] Sled et al, IEEE, 1998. [2] Shin et al., MRM, in press. [3] Hersovitch et al, JCBFM, 1985. [4] Suzuki et al, MRI, 2006.

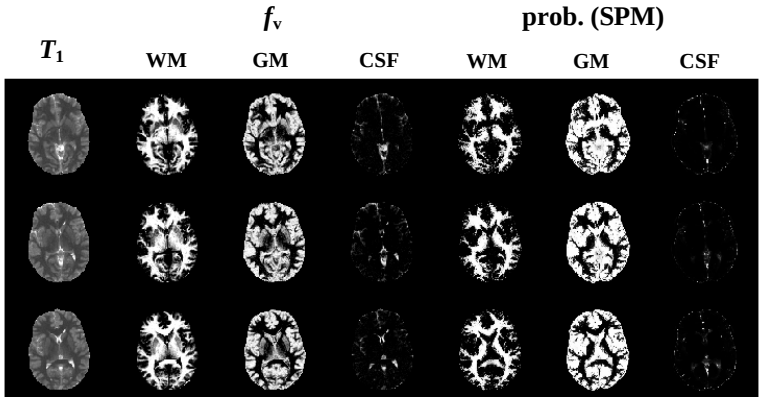

Fig 3. Representative 3 slices of T_1 maps and f_v maps are shown and compared with the probability maps using SPM. T_1 maps are presented from 0 (black) ms to 3500 (white) ms, and f_v maps and probability maps are shown from 0 to 1.

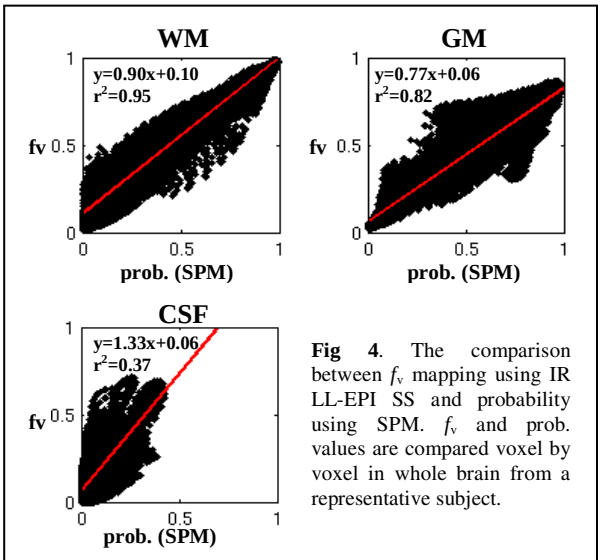

Fig 4. The comparison between f_v mapping using IR LL-EPI SS and probability using SPM. f_v and prob. values are compared voxel by voxel in whole brain from a representative subject.