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 (T1) are usually employed for tissue segmentation. However, the signal intensity of a T1-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 T1-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 T1 values. This method is insensitive to instrumental settings and can be used to address specific populations.

Methods

Fast T1 measurement: Recently a fast T1 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 (T1) is expressed as 1/τ = 1/τ0 [1-2exp(-TR/T1)]. As shown in Fig.1, after the signal intensity approaches to a steady state (M0), 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) = M0[1-2exp(-t/T1)].

Automated segmentation: A three-compartment model (WM, GM, and CSF) was used for segmentation. Tissue segmentation was defined as fractional volume (fv) measurement. The signal normalized by M0 can be expressed as:

\[ signal = \sum_{i=WM,GM,CSF} f_v(i)(1 - \exp(-TR/T1_i)) / (1 - \exp(-TR/T_{1,0}) \times (1 - 2 \exp(t/T_{1,0})), \]

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 T1 [4], T1 and T1* values in WM and GM are measured individually from the whole brain T1 histogram (see Fig 2), and T1 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 MRI 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.

Results and Discussion

From the T1 histograms, average T1 values (N=9) were measured as 921 ± 28 ms in WM and 1537 ± 32 ms in GM. Fast whole brain T1 mapping was achieved by the IR LL-EPI SS method and fv maps were obtained from the three-compartment model. Fig.3 shows the representative 3 slices of T1 and fv 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 T1 values is expected to have advantage over segmentation based on relative signal intensity in T1-weighted image. The correction of the nonuniformity in the signal intensity is not needed in the current method. Quantitative T1 maps provide larger range of contrast than T1-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.


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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 T1 values in WM and GM are calculated from two Gaussian distribution fittings (Red: WM, Blue: GM, Yellow: WM+GM, and Green: GM+CSF).

Fig 3. Representative 3 slices of T1 maps and fv maps are shown and compared with the probability maps using SPM. T1 maps are presented from 0 (black) ms to 3500 (white) ms, and fv maps and probability maps are shown from 0 to 1.

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