Sensitive and Fast T1 Mapping Based on Two Inversion Recovery Magnetic Resonance Images Acquired in a Single Scan

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Introduction: Various MRI measurements require estimates of T_1 for quantification, including arterial spin labeling perfusion imaging (1,2) and magnetization transfer imaging (3). However, multiple inversion recovery (IR) experiments require relatively long scan times and require to make an estimate of the precise negative-to-positive phase transition of the IR signal, and are generally very sensitive to image noise (4). To reduce these problems, several two-point methods (4,5) were introduced, but at the expense of dynamic range. The primary objective of this study was therefore to develop a method for T_1 mapping based on two IR images (without using Look-Locker data acquisitions (6)) so that the full signal dynamic range could be used within a very short scan time while error propagation in estimating T_1 remained at minimum. Another objective was to eliminate complications with phase transition for T_1 measurements. Using single shot echo planar imaging (EPI) (7) for data acquisition to further reduce scan time, multi-slice T_1 maps of human brain were obtained within a few seconds.

Theory: Using two IR magnitude signals, a T_1 map can be obtained according to **Eq.(1)**, where S_e, S_{IR1}, and S_{IR2} are signals from single-shot gradient-echo (GE) EPI sequence without IR-preparation, at TI_1 and TI_2, respectively. The first inversion time, TI_1, should be as short as possible to obtain a large signal of negative magnetization so that the full dynamic range of IR propagation can be utilized. The second inversion time, TI_2, should be long enough to obtain a recovered signal of magnetization from brain tissues that has sufficient signal-to-noise. T_{1m} indicates an estimated value of T_1. Note that the sign of the first signal was reversed to recover negative magnetization. To minimize the error in measuring T_{1m} of gray and white matter in human brain, first-order error propagation theory was applied to determine TI_2 values with a given minimum TI_1 (4,8). With the assumption that measurement errors of S_{IR1}, S_{IR2}, and S_e are uncorrelated and are characterized by the same standard deviation (SD) σ_S, the SD of T_{1m}, σ_{T1m}, is given by **Eq.(2)**. From this equation, the SNR of T_{1m} and S_e are defined as $SNR_{T1} = T_1/\sigma_{T1m}$ and $SNR_{Se} = S_e/\sigma_S$, respectively (9). Eq (2) also implies that if T_1 of gray matter and white matter is roughly known a-priori, TI_1 and TI_2 values can be optimized to maximize SNR_{T1} in human brain.

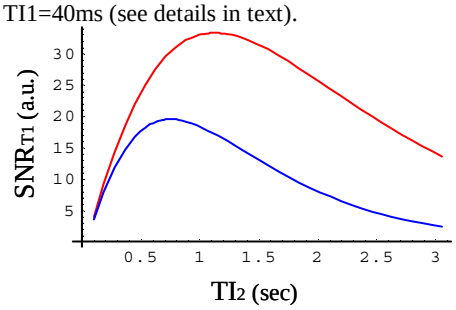
$$T_{1m} = \frac{TI_2 - TI_1}{\ln\left(\frac{S_e - (-S_{IR1})}{S_e - S_{IR2}}\right)} \quad (1)$$

$$\frac{\sigma_{T1m}}{T_1} = \left(\frac{1}{2}\right)\left(\frac{\sigma_s}{S_e}\right)\left(\frac{T_1}{TI_2 - TI_1}\right)\left\{\frac{\sqrt{\exp(-2*TI_2/T_1)+\exp(-2*TI_1/T_1)}}{\exp[-(TI_1+TI_2)/T_1]}\right\} \quad (2)$$

Methods: *Simulations*: To determine the optimal two inversion times for human brain imaging, computer simulations were performed to evaluate Eq. (2) over a range of TI_1 and TI_2, where $TI_2 > TI_1$ with the following parameters: SNR_{Se}=50 and T_1=980ms (10) for gray matter and SNR_{Se}=30 and T_1=640ms (10) for white matter in human brain at 1.5T. SNR_{se} was based on the SNR obtained from an experiment of a single-shot GE-EPI in human brain at 1.5T. *Studies on human brain*: In order to minimize motion and other transient variations between measurements, a sequence was developed to obtain three images in a single scan using a two-dimensional EPI data acquisition. A single-shot GE-EPI signal was acquired without IR-preparation to obtain S_e, followed by two acquisitions with inversion times TI_1 and TI_2 with TR=7000 ms and TE=15 ms for all three measurements. Nine normal volunteers (mean age and SD=61±15 years, age range = 37-80 years) were studied using a 1.5T MR system (Vision, Siemens, Germany). Seven 8 mm thick slices were acquired with a 3.4 x 3.4 mm^2 in-plane resolution and a 2 mm gap between slices. Inversion times of TI_1 =40 ms (the shortest experimentally possible inversion time and the highest SNR_{T1}) and TI_2 = 900 ms were chosen based on simulation results. The total acquisition time for seven slices was 28 seconds. T_{1m} was estimated for each pixel based Eq.(1).

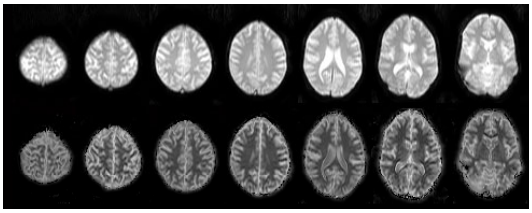
Results: Plots of SNR_{T1} as a function of TI_2 according to Eq.(2) are shown in **Fig. 1** for typical SNR_{se} values of gray matter (red) and white matter (blue) with TI_1=40ms. The shortest TI_1 in our sequence was 40ms, which yielded maximum SNR_{T1} with at TI_2 =1100 ms for gray matter and at TI_2=700ms for white matter. For in-vivo studies the average of the optimal TI_2 inversion times for gray and white matters, which was 900 ms, was used. Studies in human brain: **Fig. 2** shows single shot GE-EPI (S_e) images and corresponding T_{1m} maps from seven axial sections through the brain of a volunteer obtained in 28 seconds. The T_{1m} maps show overall reasonable contrast between gray and white matter. On average, T1 values on 9 subjects using the proposed method yielded T_{1m} values of 1094±18ms for gray matter and 746±40ms for white matter.

Fig.1. Simulation of SNR_{T1} of Eq.(2) for gray matter (red) and white matter (blue) with TI1=40ms (see details in text).



Conclusion: T_1 measurement of human brain based on two IR images utilizing the full dynamic signal range and requiring only a few seconds for acquisition yielded results similar to those previous reported (10). Furthermore, there are no phase transitions to be considered and error propagation was minimized. Therefore, this new method may be useful for obtaining T_1 values of brain tissue in clinical studies, where short scan time and simplicity of data processing are imperative.

Fig.2. Images from one normal volunteer of S_e (top) and corresponding T_{1m} map (bottom).



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