Fast High-Resolution T1 Mapping using Inversion Recovery Look-Locker Echo-Planar Imaging at a Steady State: Optimization for Accuracy and Reliability

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Introduction

Fast measurement of spin-lattice relaxation time constant (T_1) has been increasingly popular for determining pathology in brain tissues. Segmented inversion recovery Look-Locker [1] echo-planar imaging (IR LL-EPI) approaches have been used for high-resolution, whole brain T_1 mapping due to their fast acquisition. However, additional delay time between segmented LL-EPI acquisitions is needed in these techniques for the longitudinal magnetization to recover to its equilibrium state. In this study, a fast T_1 measurement sequence using IR LL-EPI at a steady state (IR LL-EPI SS) is presented. Delay time for a full magnetization recovery is not required in the sequence, saving acquisition time significantly for high-resolution T_1 mapping. Imaging parameters of the IR LL-EPI SS sequence were optimized to minimize the bias from the imperfection of excitation pulses and to maximize the accuracy and reliability of T_1 measurements.

Methods

IR LL-EPI acquisitions at steady states (IR LL-EPI SS): A LL-EPI sequence collects multiple data points in an IR period [1]. 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}), LL-EPI acquisitions are performed, each with duration of TD. With no delay time between the LL-EPI acquisitions, the signal intensity is: $S(t) = M_{SS}|1-2\exp(-t/T_1^*)|$.

Optimization of the parameters:

i) Accuracy: One of the error sources in the T_1 measurement using IR LL-EPI is the imperfect flip angle (FA) of the excitation pulses. When an unitless variable, $\tau_{TR}=TR/T_1$, is introduced, the accuracy of measured $R_1=1/T_1$ due to the imperfect excitation can be expressed as $A_\gamma = (R_{1,measured}-R_{1,true})/R_{1,true} = \ln(\cos(\alpha)/\cos(\gamma\alpha))/\tau_{TR}$, where γ is the efficiency of the excitation pulse. The accuracy of T_1 measurement was simulated with γ=0.814, which represent the lowest 99% of the B1 efficiency values observed in brain imaging [2].

ii) Reliability: Using Monte-Carlo simulation, signal relaxation in the IR period was simulated 10^4 times, with appropriate noise added and with various FA and τ_{TR} values. From the simulated data, reliability was evaluated by the standard deviation of measured R_1 divided by true R_1(rSD).

Results and Discussion

Fig.2 shows the accuracy ($A\gamma$) and reliability (rSD) of T_1 measurement using IR LL-EPI SS, as functions of FA and τ_{TR}. To maximize the reliability and minimize the bias of the measurement, optimal FA was determined from this analysis. Considering T_1 values of brain tissues at 3T, FA of 16° was chosen by minimizing $A\gamma+2.33|rSD|$ in the range of $0.25\leq \tau_{TR} \leq 0.4$.

With a fixed number of slices, or a brain coverage, the total running time is dependent on TR. Tab.1 shows the performance of IR LL-EPI SS sequence as a function of TR, with FOV=256×192 mm^2, matrix =256×192, thickness=4 mm (voxel size=1×1× 4mm^3), and 28 slices. TR is important for fast high-resolution T_1 mapping, because it affects the reliability and total acquisition time. In this study, the optimal TR was chosen as 400ms. Relative to the results at TR=400ms, TR of 300 ms gives a 9% improvement in reliability, while TR of 500 ms losses 10% of reliability. However, the total running time increases by 66% with TR=300 ms and decreases by 21% with a TR=500ms, compared to TR=400 ms. The accuracy and reliability of IR LL-EPI SS were compared with a conventional IR LL-EPI technique and there was no significant difference between them. A representative T_1 maps with the optimized imaging parameters from a healthy subject is shown in Fig.3.

Conclusion

Fast high-resolution T_1 mapping can be achieved by the IR LL-EPI SS method, which does not require an additional time delay between IRs and therefore shortens the total acquisition time. Compared with IR LL-EPI, the IR LL-EPI SS method preserves similar accuracy and reliability, while saving 20% in acquisition time. The proposed fast T_1 mapping technique was demonstrated on in vivo human brains, and provided an imaging time of 8.6 s per slice.

Reference 1. Look & Locker, RSI, 1970. 2. Samson et al., MRI, 2006.

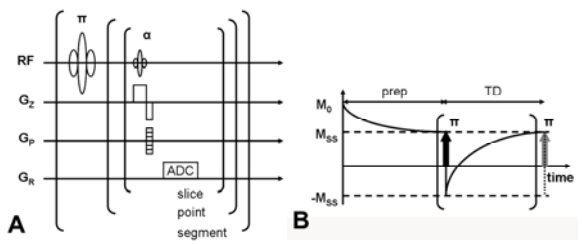

Fig 1. IR LL-EPI SS sequence diagram (A) and acquisition paradigm (B). In (A), after the inversion pulse, a series of α° excitation RF pulses are applied for LL acquisition. In (B), before the first LL acquisition, a series of α° preparation pulses are applied to allow the longitudinal magnetization to reach a steady state. The time duration for each LL acquisition is TD.

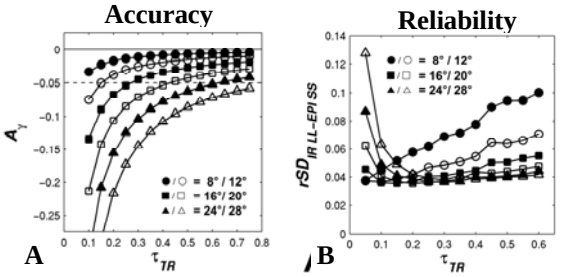

Fig 2 Accuracy (A) and reliability (B) of T_1 measurement at various τ_{TR} and FA.

Tab 1. Performance of IR LL-EPI SS at different TRs.

TR (ms)	lines per acquisition	Total Time (min)	Time per slice (s)	Reliability (%)
300	5	6:40	14.3	4.0±0.2
400	9	4:00	8.6	4.2±0.2
500	11	3:10	6.8	4.6±0.5

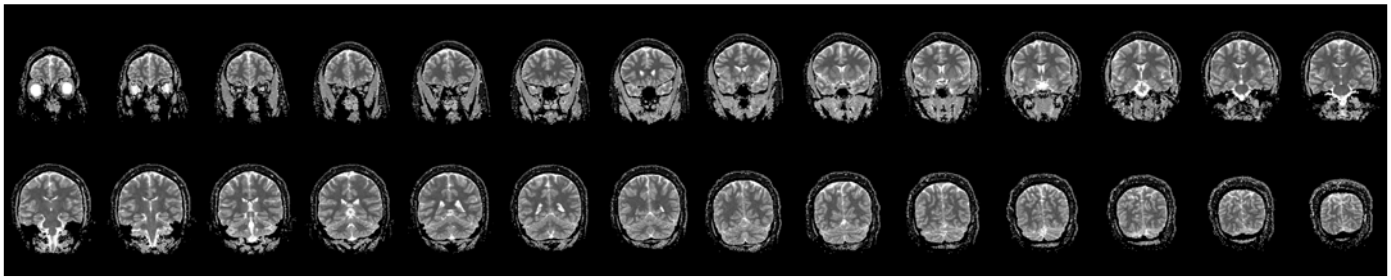

Fig 3. Representative T_1 maps of 28 brain slices are presented from 0 (black) to 3500ms (white), which were acquired at 8.6.s per slice.