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 (T1) 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 T1 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 T1 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 T1 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 T1 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 (T1) can be expressed as 1/T1=1/TR-ln(cos(α)/sin(γ))/TR. As shown in Fig.1, after the signal intensity approaches to a steady state (M0s), 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) = M0[1-2exp(-t/T1)]

Optimization of the parameters:

i) Accuracy: One of the error sources in the T1 measurement using IR LL-EPI is the imperfect flip angle (FA) of the excitation pulses. When an unitless variable, τRF=TR/T1, is introduced, the accuracy of measured R1=1/T1 due to the imperfect excitation can be expressed as Aα = (R1(true)-R1(measured))/R1(true) = ln(cos(α)/cos(γ))/τRF, where γ is the efficiency of the excitation pulse. The accuracy of T1 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 τRF values. From the simulated data, reliability was evaluated by the standard deviation of measured R1 divided by true R1(rSD).

Results and Discussion

Fig.2 shows the accuracy (Aβ) and reliability (rSD) of T1 measurement using IR LL-EPI SS, as functions of FA and τRF. To maximize the reliability and minimize the bias of the measurement, optimal FA was determined from this analysis. Considering T1 values of brain tissues at 3T, FA of 16° was chosen by minimizing Aβ<2.33[rSD] in the range of 0.25<τRF<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=256x192 mm², matrix =256x192, thickness=4 mm (voxel size=1x1x 4mm³), and 28 slices. TR is important for fast high-resolution T1 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 loses 10% of reliability. However, the total running time increases by 66% with TR=300ms and decreases by 21% with a TR=500ms, compared to TR=400ms. 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 T1 maps with the optimized imaging parameters from a healthy subject is shown in Fig.3.

Conclusion

Fast high-resolution T1 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 T1 mapping technique was demonstrated on in vivo human brains, and provided an imaging time of 8.6 s per slice.

Reference


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 T1 measurement at various τRF and FA.

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

<table>
<thead>
<tr>
<th>TR (ms)</th>
<th>lines per acquisition</th>
<th>Total Time (min)</th>
<th>Time per slice (s)</th>
<th>Reliability (%)</th>
</tr>
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<tbody>
<tr>
<td>300</td>
<td>5</td>
<td>6:40</td>
<td>14.3</td>
<td>4.0±0.2</td>
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<tr>
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<td>9</td>
<td>4:00</td>
<td>8.6</td>
<td>4.2±0.2</td>
</tr>
<tr>
<td>500</td>
<td>11</td>
<td>3:10</td>
<td>6.8</td>
<td>4.6±0.5</td>
</tr>
</tbody>
</table>

Fig 3. Representative T1 maps of 28 brain slices are presented from 0 (black) to 3500ms (white), which were acquired at 8.6 s per slice.