A fast, quantitative $T_{1\rho}$ imaging method

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Introduction

Rotating frame relaxation measurements have been performed mainly by adding spin-lock preparation pulse(s) prior to the imaging sequence. Continuous wave (CW) on resonance $T_{1\rho}$ is typically performed with a preparation pulse containing a 90° hard or adiabatic half passage pulse prior and after a CW spin-lock pulse. During adiabatic full passage pulses, like hyperbolic secant (HS) pulses, spins are locked along B_{eff} during the pulse and depending on the initial condition of magnetization, $T_{1\rho}$ and/or $T_{2\rho}$ relaxation takes place. Typically, pulses are repeated to incrementally increase spin-lock time and allow $T_{1\rho}$ and/or $T_{2\rho}$ quantization. Depending on RF-power, specific absorption rate may limit applications so reducing the total number of preparation pulses may alleviate this problem. The purpose of this study was to develop a faster pulse sequence with fewer RF pulses for rotating frame relaxation quantization.

Materials and methods

All experiments were carried out using 9.4 T magnet (Oxford Instruments) equipped with a Varian Direct Drive console with a quadrature volume transceiver (Rapid Biomedical). The pulse sequence based on gradient echo design was modified to include four HSn pulses, after which a single phase encoding step was acquired. This was repeated four times (N=4) to obtain a $T_{1\rho}$ weighted signal intensity curve with incrementally increasing spin-lock time. The HSn pulse parameters for sequence testing were set to n=1, $\gamma B_1/(2\pi)$=2.5 kHz, and time duration 5 ms leading to train length (TL) of 20 ms for 4-pulse segments. Imaging time (IT) (Fig. 1) of the sequence was set to 5.6 ms, TE=2.1 ms and relaxation delay to 2 s making a total imaging time of 4 minutes. The crusher gradient amplitude (G_{crush}) was 12 Gauss/cm and the flip angle (α)=20°. As a reference method, a similar train of HSn pulses was added in front of the spin echo read out (TR=2 s, TE=12 ms, total imaging time of 17 minutes). $T_{1\rho}$ relaxation times were measured from a slice containing *cortex*, *hippocampus* and *thalamus* in intact c57bl male mouse brains (n=4 for the new method and n=3 for the reference method). Data from the developed method were corrected for the flip-and-crush condition using the equation $S_{mc}=S_m\cos^{-m}(\alpha)$, where S_m is measured signal intensity in the mth image. $T_{1\rho}$ relaxation times were fitted using a single mono exponential function.

Results

The data acquired with the developed sequence resulted in similar $T_{1\rho}$ values as the conventional spin echo method with a $T_{1\rho}$ preparation pulse train (Fig. 1.). Relaxation times from *cortex*, *hippocampus*, and *thalamus* were 115±11 ms, 118±12 ms, and 106±10 ms with the developed method and 112±7 ms, 117±6 ms, and 106±3 ms with the spin echo method, respectively. No statistically significant differences were found between the methods (p>0.6) in any regions of interest. Standard deviation of $T_{1\rho}$ divided by mean $T_{1\rho}$ from cortical region of interest was ≈2 times higher in new method compared with spin echo acquisition corresponding to four times longer imaging time in spin echo.

Discussion and Conclusions

The developed method produces artifact free images with the chosen amplitudes of G_{crush}. The flip-and-crush condition leads to additional signal loss during the $T_{1\rho}$ weighting pulse train which leads to 37% smaller relaxation times than taking into account flip-and-crush in this data. The HS1 pulse was selected only for demonstration purposes and might be replaced by other RF pulses to produce $T_{1\rho}$ and/or $T_{2\rho}$ weighting, acquisition of several incremented spin-lock times within one TR allows faster quantization of $T_{1\rho}$ and/or decreased specific absorption rates of $T_{1\rho}$ measurements when signal to noise to time ratio is sufficient. Therefore, the developed method paves the way for clinical use of quantitative $T_{1\rho}$ measurements.

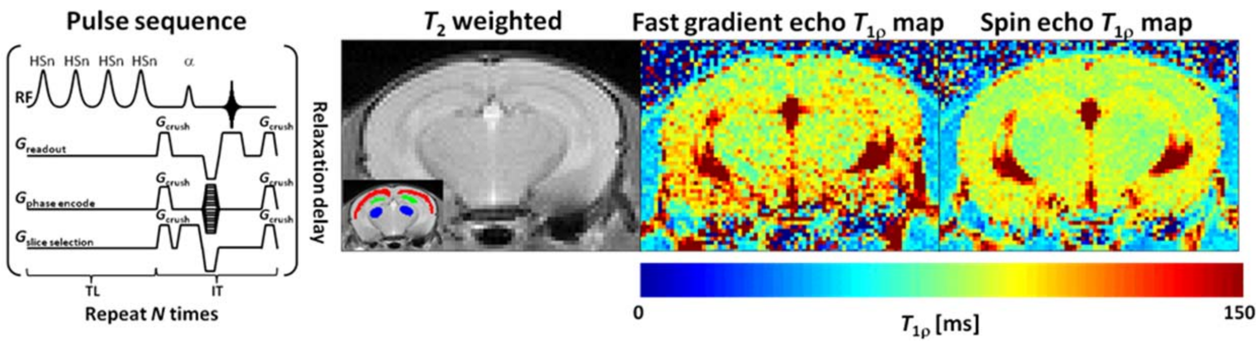

Fig. 1 Pulse sequence diagram, T_2 weighted spin echo image with insert showing region of interests (*cortex* red, *hippocampus* green, *putamen* blue), $T_{1\rho}$ maps obtained with a fast gradient echo based method (total imaging time = 4 min, std/$T_{1\rho}$(cortex)=0.11) and with a preparation pulse in front of the spin echo sequence (total imaging time = 17 min, std/$T_{1\rho}$(cortex)=0.05).