RAPID T_1 DETERMINATION WITH OPTIMIZED INVERSION RECOVERY SEQUENCE

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Introduction: There is continuing interest in rapid quantitative measurements of spin-lattice relaxation time (T_1). Conventionally, an inversion-recovery (IR) sequence is used to determine T_1, with logarithmic spacing of inversion recovery times (t_i), a long pre-delays (t_d), and with data fitted to a single-exponential equation. Spin-echo (SE) or fast-spin-echo (FSE) techniques may be applied for the read-out. In this study, a fast T_1 measurement sequence using the IR-FSE technique is presented, as shown in Fig. 1. Cramer-Rao lower bounds (CRLB) were calculated to search for the global optimal acquisition scheme by varying both t_i and t_d (conventional methods only vary t_i). The optimal acquisition schemes were verified by Monte Carlo simulations and experimental results. The effect on the T_1 precision efficiency of varying the number of sampling points was also investigated. It is shown that varying t_i and t_d increases the precision efficiency to ~ 2.5 times over the conventional method and that only three data points are required to determine T_1.

Methods: For an IR sequence with SE or FSE readout, as shown in Fig. 1, the signal is given by:

$$S = M_0[S_f(1-e^{-t_d/T_1})e^{-t_i/T_1} + 1 - e^{-t_i/T_1}] \qquad [1]$$

where M_0 is the magnetization of the equilibrium state, and S_f (≈ -1) quantifies the effect of the inversion pulse. The goal of the optimization is to find a set of sample points, $x_1, \ldots, x_N$ that minimize the variance of the fitted parameters, where x is a combination of t_i and t_d [1]. The objective function includes two components: 1) CRLB, which minimizes uncertainties of the fitted qMT parameters; 2) the time cost of the acquisition scheme, to account for the expected sqrt(time) dependence of the SNR. A simulated annealing algorithm is used to search for the optimal solution [2]. To reduce the possibility of local minima biasing our results, the optimization process was repeated several times from different random starting points. Optimizations were performed for a typical set of parameters and for a range of parameters. The effect of varying the number of sampling points was also investigated. It was found that the minimum number of sampling points is three, which is expected. Monte Carlo simulations were performed to compare the optimal schemes with the conventional scheme, with the same total acquisition time and Gaussian noised introduced to each data point. Measurements were performed on $MnCl_2$ samples of 0.058 mM and 0.116 mM, and on an *ex vivo* male Wistar rat brain on a 9.4 T Varian magnet. The rat brain was fixed with formalin at 4°C for over 7 days and was washed with PBS for over 48 hours with four PBS solution changes at room temperature [3].

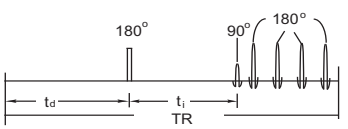

Fig. 1. IR-FSE sequence.

Results: Fig. 2 shows a comparison of numerical simulations employing (a) a conventional acquisition scheme which only varies t_i with a constant t_d of 5 s and (b) the new method described in this abstract which makes optimized variations in t_i and t_d. Fig. 3 shows a comparison of precision efficiencies from CRLB predictions, Monte Carlo simulations, and measurements on $MnCl_2$ samples using a series of acquisition schemes: (a) a ten-point conventional scheme with t_i logarithmically varied between 4 ms and 6 s, and t_d of 6 s. Schemes (b) and (c) are optimized by varying t_i values with a constant optimal t_d of 1s. Scheme (b) is optimized for parameter values of $M_0 = 1$, $T_1 = 1$, and $S_f = -1$. Scheme (c) is optimized for parameter range values of $M_0 \in [0.5, 1.5]$, $T_1 \in [0.5, 1.5]$, and $S_f \in [-0.85, -1]$. Schemes (d – i) are optimized by varying both t_i and t_d values. Schemes (b) (d) (f) (h) are optimized for a single parameter set, as in (b), with numbers of sampling points of 10, 5, and 3, respectively. Schemes (e) (h) (i) are optimized for a range of parameter values as in (c), with numbers of sampling points of 10, 5, and 3, respectively. The estimated values and uncertainties are calculated from the mean and standard deviation of the pixels in the region of interest. Fig. 4 shows the measured T_1 map of the *ex vivo* rat brain sample.

Discussion: It is illustrated in Fig. 2 that the optimal scheme produces much smaller uncertainties in measured T_1 for the same total acquisition time. The higher precision efficiencies of optimal schemes are shown in Fig. 3 in more details, by comparing CLRB predictions, Monte Carlo simulations and experimental results. The optimal schemes have precision efficiencies ~ 2.5 times greater than the conventional method and ~1.25 times greater than when optimizing t_i only with a single t_d value. The optimal three-point scheme has been further demonstrated by an ex vivo measurement, as shown in Fig. 4. The contrast between white matter and gray matter is clearly seen. This work has provided an improved means for rapid T_1 determination.

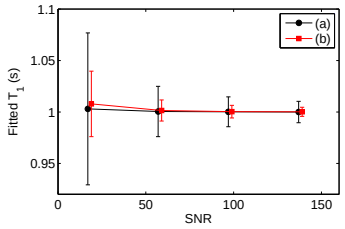

Fig. 2 Monte Carlo simulations of T_1 values with (a) a 10-point conventional scheme, and (b) An optimal three-point scheme.

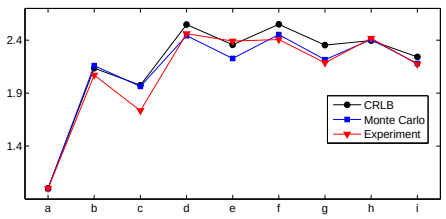

Fig. 3 A comparison of precision efficiencies from CRLB, Monte Carlo simulation and experimental results for a series of acquisition schemes on $MnCl_2$ samples.

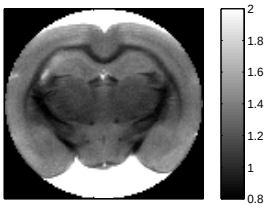

Fig. 4 Measured T_1 map of an *ex vivo* rat brain sample using an optimized three-point acquisition scheme.

References: [1] Li K et al. Proc Intl Soc Magn Reson Med. 2009; 17: 4500. [2] Li K et al., Magn Reson Med (in review). [3] Shepherd TM et al. Magn Reson Med 2009;62(1):26-34.

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