Measuring T1 and T2 and proton density in 3 acquisitions: the Tri-τ method

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INTRODUCTION. T_1 and T_2 are typically determined by separate partial saturation (PS) or inversion recovery and spin-echo (SE) experiments. We propose a new method to measure both T_1 and T_2 in just three acquisitions, without using echoes or varying the repetition period T_R. Instead, T_2 is measured by varying the pulse length (τ) of an adiabatic B_1-independent rotation (BIR-4) pulse in two of the acquisitions, based on the fact that long adiabatic excitation pulses are prone to T_2 decay [1,2]. T_1 is determined by varying the flip-angle in two acquisitions, analogous to the dual-angle method [3]. Thus, this 3-acquisition "Tri-τ" method employs an α hard pulse excitation, a β short-duration BIR-4 pulse, and a β long-duration BIR4 excitation. The method is validated with T_1 and T_2 SE and PS measurements on phantoms.

THEORY. Because during BIR-4 pulses the magnetization spends time in the transverse plane and is subject to T_2 decay [1], T_2 can be measured from two acquisitions employing long and short BIR-4 pulses of duration τ_3, and τ_2, essentially independent of flip-angle β [2]. Adding a third acquisition with a different flip-angle α yields T_1 provided the sequences are applied with a (single) $T_R \le T_1$ to permit adequate T_1 attenuation and resolution. Thus the Tri-τ method acquires: a first signal S_1 with a conventional short ($\tau << T_2$) α RF excitation pulse; a second signal S_2 with a β BIR-4 pulse of duration τ_2; and a third signal S_3 with a β BIR-4 pulse of length $\tau_3 = 2\tau_2$. With $E_1 = \exp(-T_R / T_1)$, the three steady-state signals are: $S_1 = \left[M_0(1-E_1)\sin\alpha\right]/(1-E_1\cos\alpha)$; $S_2 = \left[M_0(1-E_1)E_{p2}^{xy}\sin\beta\right]/\left(1-\cos\beta E_1 E_{p2}^{z}\right)$ [3]; $S_3 = \left[M_0(1-E_1)E_{p3}^{xy}\sin\beta\right]/\left(1-\cos\beta E_1 E_{p3}^{z}\right)$ with E_p^{xy} and E_p^{z} as the transverse and longitudinal attenuation factors. From numerical simulations with practical BIR-4 pulses and β<80°, $E_p^{xy} = E_p^{z} = E_p = \exp(-g\cdot\tau/T_2)$, $E_{p3} = (E_{p2})^2$, and the equation set simplifies to a quadratic with solutions of E_{p2} and E_1, yielding $T_1 = -T_R/\ln(E_1)$ and $T_2 = -(g\cdot\tau_2)/\ln(E_{p2})$, where g is a constant reflecting the time spent by the magnetization in the transverse plane.

METHODS. Numerical simulations based on the Bloch equations were performed with B_1=20μT, f_{max}=15kHz at 3T. BIR-4 pulse lengths were varied over 5≤τ≤40ms to determine g as a function of T_1, T_2 and flip-angle. Monte-Carlo simulations were performed to determine the accuracy of the Tri-τ method at signal-to-noise ratio (SNR)=50, with experimental values of $\tau_3 = 2\tau_2$=20ms, T_R=0.3s.

The Tri-τ method was validated experimentally in ^{1}H NMR studies of 6 $CuSO_4$-doped gel phantoms on a Philips 3T Achieva scanner with 219≤T_1≤890ms and 31≤T_2≤129ms, as determined by standard SE and PS methods. S_1 was acquired with α =15° 75μs hard pulse, S_2 and S_3 are excited by 60° BIR4 pulses.

RESULTS. The Bloch simulations yielded g=0.81 for T_1=1s, 14≤T_2≤120ms and θ <80°, varying less than 1.5% for 120≤T_1 ≤1000ms. The Monte Carlo simulations of the Tri-τ method showed that T_2 could be measured with a mean error of -10% to 2% for T_2≤80ms and 0.1≤T_1≤1s (Fig1). The error in T_1 was ≤1%±15%(SD) for 0.3≤T_1≤1s, 30≤T_2≤130ms (Fig 2).

T_2 and T_1 values measured from the Tri-τ experiments on phantoms are compared with SE and PS T_1 and T_2 values in Figs 3, 4. The results show good agreement for all phantoms.

DISCUSSION. Because the proton density derives directly from the fully-relaxed signal, the Tri-τ method offers the potential for obtaining all of the T_2, T_1 and signal density information with just three acquisitions–arguably the minimum possible. The caveat is that the method requires accurate setting and knowledge of the flip-angles. This new method can potentially save time and simplify relaxation measurements. Extension of the approach to MRI is currently underway.

Fig1. Monte Carlo error, T_1

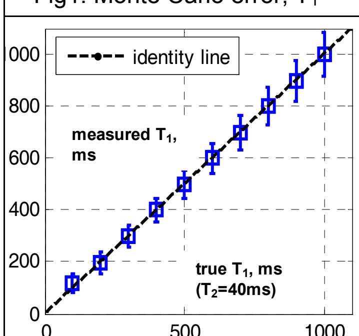


Fig2. Monte Carlo error, T_2

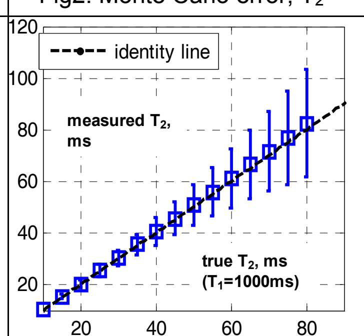


Fig3. Tri–τ vs. PS T_1

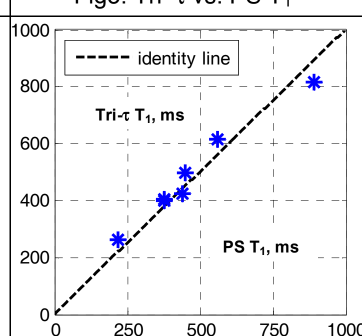
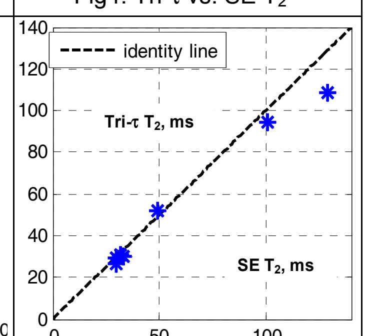


Fig4. Tri-τ vs. SE T_2



1. El-Sharkawy AE, et al. Magn Reson Med 2009; 61:785-795. 2. Wang G, *et al.* Proc. ISMRM 2011; 19: 2174.
3. Bottomley PA, et al. J Magn Reson B,104 (1994);159-1671. *This work is supported by NIH grant R01 EB7829.*