Single-Shot Proton Density, T_1 and T_2 Quantification with Radial IR TrueFISP: Effect of Magnetization Transfer and Long RF Pulses

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Introduction: A promising approach for the simultaneous quantification of proton density, T_1 and T_2 is the IR TrueFISP sequence proposed by Schmitt et al. [1]. This sequence consists of an inversion pulse followed by a series of TrueFISP acquisitions; the signal in these images follows a quasi-relaxation curve towards the steady-state. Parameters can then be obtained from a mono-exponential fit to the series of images. However, segmented acquisition is usually necessary, thereby considerably increasing the total acquisition time. The goal of this work was to obtain proton density, T_1 and T_2 maps using a single shot acquisition per slice with a clinically relevant spatial resolution. To this end, the IR TrueFISP sequence was combined with a recently proposed radial trajectory with golden-ratio based profile order [2] and a view sharing technique [3]. Early implementations of this technique show that the measured relaxation rates depend strongly on certain acquisition parameters (especially TR, pulse duration, and flip angle). A systematic overestimation of T_1 can be seen, and this is hypothesized to relate to the recently reported influence of magnetization transfer (MT) on the bSSFP signal [4]. This effect was analyzed by varying the pulse duration and TR. However, prolonged RF pulses can again lead to another problem: T_2 relaxation is effectively suspended while the steady state passes a longitudinal alignment during the RF pulse. In an IR TrueFISP exp., this leads to an overestimation of T_2. This effect could be taken into account, and parameter maps accurately estimated, using a recently proposed extension to the Bloch equations [5].

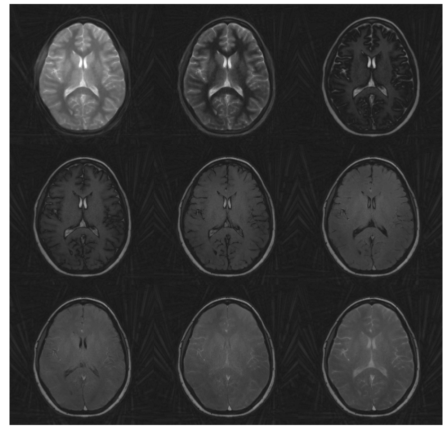

Fig. 1: Representative time frames from the single-shot IR-TrueFISP experiment.

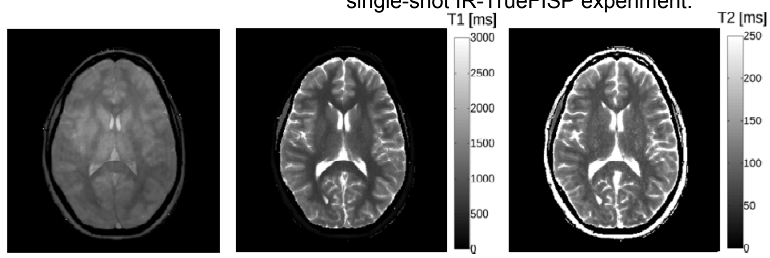

Fig. 2: Proton density, T_1 and T_2-Maps from the 3 parameter fit.

Methods: All experiments were performed at 1.5 T (Siemens Espree) with a 32-channel head array on a healthy volunteer. After non-selective adiabatic inversion, the return to equilibrium was observed with a radial TrueFISP sequence with golden-ratio based profile order. The experiment was repeated with different pulse durations and shortest realizable TR (pulse dur.=0.8/1.6/2.4/3.2/4.0 ms, TR=3.98/4.78/5.58/6.38/7.18 ms, flip angle=45°, 256^2 matrix, FoV=220x220 mm², sl. thickn.=6 mm). In total, 64 time frames were reconstructed using a k-space weighted image contrast (KWIC) filter [6] and NUFFT gridding [7]. Proton density, T_1 and T_2, were then obtained from a 3-parameter fit [1]. T_2 was corrected using the following extended T_2 relaxation term (with the RF pulse duration T_{RF}, and the effective longitudinal residence time $\xi \cdot T_{RF}$, as given in [5]):

$$E_2 = e^{-TR/T_2} \xrightarrow{\text{finite RF}} \widetilde{E}_2 = e^{-(TR-\zeta T_{RF})/T_2}$$

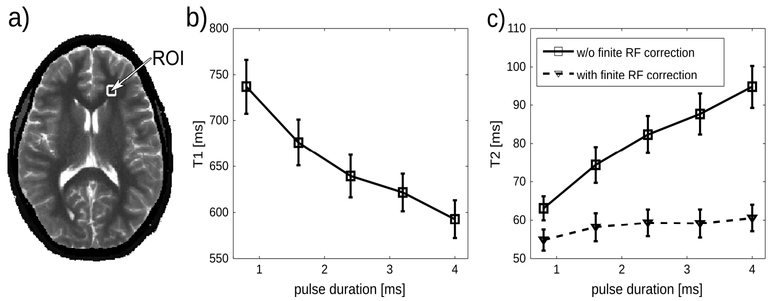

Fig. 3: (a) ROI over 81 pixels in relatively homogeneous white matter, used for further analysis. (b) T1, and (c) T2 and finite rf corrected T2 depending on pulse duration. The error bars indicate the standard-deviation in the ROI.

Accordingly, the approximate expressions for the steady state and the T_1* relaxation [1] only need slight modification (in bold):

$$S_{stst} = M_0 \sin(\alpha)\left[(T_1/T_2 \cdot \mathbf{(1-\zeta T_{RF}/TR)}+1) - \cos(\alpha)(T_1/T_2 \cdot \mathbf{(1-\zeta T_{RF}/TR)}+1)-1)\right]^{-1} \qquad T_1^* = [\cos^2(\alpha/2)/T_1 + \sin^2(\alpha/2)/T_2 \cdot \mathbf{(1-\zeta T_{RF}/TR)}]^{-1}$$

Either the data can then be directly fitted to these equations, or T_2 can be retrospectively corrected (by multiplying with (1- ξT_{RF}/TR)).

Results: Representative reconstructed images from the IR time series are shown in Fig. 1. Fig. 2 shows obtained parameter maps (for pulse duration = 1.6 ms and TR = 4.78 ms). The effect of the pulse duration on the parameter quantification is shown in Fig. 3.

Discussion and Conclusion: The results show that it is possible to obtain T_1, T_2 and relative proton density from a single IR TrueFISP experiment in under 6 s per slice. It was also demonstrated that MT effects can lead to a substantial overestimation of the T_1 relaxation time (Fig. 3 b), but that this effect can be reduced by prolonging the RF pulse (thereby reducing RF pulse power). Without additional corrections, this prolonged RF pulse can lead to an overestimation of the T_2 relaxation time, due to the violation of the assumption of instantaneous RF rotations. As shown here, this effect can be relatively easily corrected. These corrections should enable high speed, high accuracy mapping of MR relaxation parameters *in vivo*.

References: [1] Schmitt P et al. Magn Reson Med. 2004 Apr;51(4):661–667., [2] Winkelmann S et al. IEEE Trans Med Imaging. 2007 Jan;26(1):68-76, [3] Yutzy SR et al., Proc. ISMRM, 2009; #2765. [4] Bieri O, Scheffler K. Magn Reson Med. 2006;56(5):1067-1074., [5] Bieri O, Scheffler K. Proc. ISMRM, 2009; #2793., [6] Song HK, Dougherty L. Magn Reson Med. 2000 Dec;44(6):825-832. 1. [7] Fessler JA, J Magn Reson. 2007 Oct;188(2):191-5.