Rapid 3D Relaxation Time and Proton Density Quantification Using a Modified Radial IR TrueFisp Sequence

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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, observing a quasi-relaxation towards the steady-state. However, this sequence requires a delay between individual segments in order to allow the magnetization to recover. For adequate results this delay has to be on the order of 5 to 10s, resulting in relatively long scan times. Recently, a modified IR TrueFISP method for simultaneous T_1, T_2 and spin density quantification has been proposed, which does not necessitate relaxation delays [2]. The aim of this work was to develop a method for rapid parameter quantification in 3D. To this end, the modified IR TrueFISP method was combined with a 3D radial stack-of-stars acquisition with golden-ratio based profile order [3].

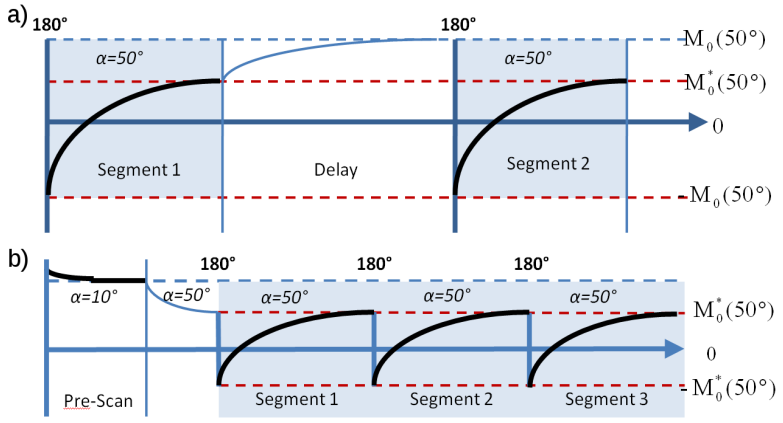

Fig. 1: Simplified diagram of the signal evolution during a) a conventional IR TrueFISP experiment, and b) a modified IR-TrueFISP experiment without relaxation delays between segments. In this case, a pre-scan is required to obtain M_0.

Theory: The signal in an IR TrueFISP as proposed by Schmitt et al. [1], follows a simple exponential relaxation curve (Fig.1a):

$$M(t) = M_0^* \cdot \left(1 - INV \cdot \exp\left(-\frac{t}{T_1^*}\right)\right) \qquad INV = 1 + \frac{M_0}{M_0^*} \qquad [1]$$

When the relaxation delay between individual segments is removed, the relaxation can be similarly described using only 2 parameters (Fig.1b):

$$M(t) = M_0^* \cdot \left(1 - 2 \cdot \exp\left(-\frac{t}{T_1^*}\right)\right) \qquad [2]$$

The missing parameter M_0 can be obtained in good approximation from a separate TrueFISP scan with low flip angle.

Methods: All experiments were performed on a 1.5 T clinical scanner (Siemens Avanto) with a 12-channel head array on a healthy volunteer. First, a TrueFISP experiment with small flip angle was acquired to determine the spin density (flip angle=10°, TR=3.6 ms, FoV=220x220x80 mm³, matrix size=192x192x40 (+20% slice oversampling), voxel size=1.1x1.1x2.0mm³, 401 projections, total acq. time = 1:10 min). After this pre-scan and a dummy scan, 48 adiabatic inversion pulses (one segment per partition), were each followed by a 5 s radial TrueFISP readout with golden-ratio based profile order (flip angle = 50°, 1390 projections per segment, total acq. time = 4:07 min, all other parameters as in pre-scan). To reduce Gibbs ringing, a Hamming filter was applied in partition direction prior to Fourier transformation. Individual time frames for each partition were then reconstructed using a k-space weighted image contrast (KWIC) filter [4] and NUFFT gridding [5]. The pre-scan was reconstructed similarly without KWIC filtering. M_0^* and T_1^* were then obtained from a pixel-by-pixel fit to eq. [2], and T_1 and T_2 calculated according to ref. [1].

Results: Spin density, obtained from the pre-scan, and T_1 and T_2 maps calculated from the fit are shown in Fig. 2 for three different orientations.

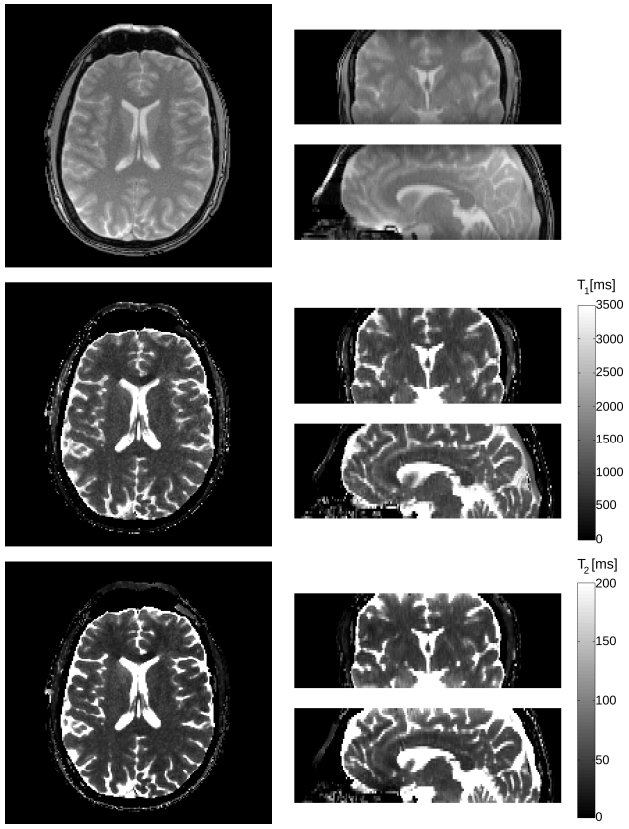

Fig. 2: Spin density, obtained from a pre-scan, and calculated T_1 and T_2 maps for three orientations (same 3D dataset).

Discussion and Conclusion: Scan time in segmented IR TrueFISP can be significantly reduced by eliminating the delay between individual segments. Combined with view-sharing, this allows the 3D quantification of M_0, T_1, and T_2 in less than 6 min. Since the steady-state in gray and white matter is reached 2-3s after inversion, scan time can be additionally reduced by shortening the acquisition time between segments (i.e. acquiring fewer projections). While this leads to quantification errors in long T_1 species (e.g. CSF), these can potentially be accounted for by adding a third parameter to the fit. Notably, the additional degree-of-freedom will lead to a slight increase of noise in the parameter maps. Future work will focus on further improvements towards an isotropic resolution of 1mm³ in an acceptable scan time, by employing parallel imaging and/or constrained reconstruction methods.

References: [1] Schmitt P et al. Magn Reson Med. 2004;51:661–7. [2] Breuer FA et al. Proc. ESMRMB, 2009. #183. [3] Winkelmann S et al. IEEE Trans Med Imaging. 2007;26:68-76. [4] Song HK, Dougherty L. Magn Reson Med. 2000;44:825-32. [5] Fessler JA, J Magn Reson. 2007;188:191-5.