ACCURATE T1 AND T2 MAPS OBTAINED WITH IR-TRUEFISP CALIBRATED BY A PATIENT DRIVEN MODEL

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Introduction: As the cure rate for childhood Acute Lymphoblastic Leukemia (ALL) approaches 95%, an increasing amount of research is being devoted to studying the long-term effects of the treatment for ALL which can lead to a variety of debilitating side effects, including neurocognitive deficits. Analysis of brain morphology of ALL survivors has shown that these patients display white matter (WM) volume losses and failure to develop WM at an age appropriate rate [1,2]. Reliable methods to quantify WM volumes have been established using MRI [3]. These methods involve lengthy scan times and require the co-registration of separately acquired T1, T2, and proton density (PD) maps. A potential shorter alternative is IR-TrueFISP [4], an inversion recovery prepared balanced steady state free precession (SSFP) sequence that has recently attracted attention as a technique to simultaneously quantify tissue relaxation parameters in a single acquisition. The use of IR-TrueFISP in WM volume quantification would eliminate the need for co-registration of multi-parameter images and accelerate the imaging process, allowing for higher patient throughput and improved image quality due to decreased head movement. One problem with IR-TrueFISP is its sensitivity to variation in the RF excitation pulse [5]. Thus, modifications to the original technique have been proposed to account for this issue, which however extend the measurement time significantly [6]. In this work we present an alternative approach that permits the use of the original, fast IR-TrueFISP experiment for quantitative MRI. Specifically, we developed a model for the transformation of IR-TrueFISP derived relaxation parameters in a large ALL patient data set toward gold standard reference signals by density-varying calibration functions fitted through a natural cubic spline.

Methods: 63 patients treated for ALL underwent an imaging exam after informed consent has been obtained. Reference T1 and T2 maps were generated by acquiring four sets of IR-TSE images at varying inversion times (TI = 100, 500, 900, and 2330 ms), total imaging time (TA) was 6:08min. For T2 quantification, a multi-echo SE sequence was used, with 16 TEs ranging from 22.5-360 ms and TA 6:28 min. PD images were acquired with a dual spin-echo sequence (TR = 3500ms, TE_1 = 17ms, TE_2 = 102ms, TA was 9:36min). This leads to a total measurement time of about 22min for the conventional technique. The IR-TrueFISP sequence incorporated an adiabatic inversion pulse for magnetization preparation and a segmented TrueFISP experiment for sampling of the relaxation curve. Imaging parameters were TR 5.4 ms, TE 2.7 ms, flip angle 50°. Each segment consisted of 21 phase encoding steps, and 50 segments were acquired during the recovery of the magnetization. 9 repetitions were necessary to fill k-space. The time between subsequent inversion pulses was 10 sec and TA was 3:06 min. A mono-exponential 3-parameter fit to the IR-TrueFISP signal recovery curve generated T1, T2, and M_0 maps using the analytical equations described in [4]. Two slices were acquired with either technique.
A model was built which can transform the original IR-TrueFISP T1 and T2 signal to be closer to the reference signal by use of a calibration function $\delta(x) = \sum_{k=1}^{K} \theta_k B_k(x)$, where x is the signal density, K is the number of knots, B_ks are the basis functions, and Θ_k are the scalar coefficients of the basic functions.

δ was assumed to be signal density-dependent and fitted through a natural cubic spline. The spline knots are pre-specified and placed evenly over the range of high frequency signals. After calibration, the empirical distribution of the reference signal is compared with that of the calibrated IR-TrueFISP signal. The use of empirical distributions can partially avoid the dependence among the image data and can also account for patient motion during the exam. Both L1 and L2 criteria have been applied to minimize the distance between the signal from the conventional technique and the calibrated IR-TrueFISP signal, however, L2 overfits the data and L1 was chosen with reasonable performance [7]. Two-thirds of the subjects were randomly sampled as training dataset and used for model fitting, while the other 21 subjects were used as validation data. For every slice of each validation subject, 5 ROIs (gray and white matter regions of the right and left hemisphere + 1 CSF region) were selected for the assessment of our model. The fitting errors defined as percentage deviation of original/calibrated signal from the reference signal were computed for all the pixels within the ROIs.

Results: Table 1 summarizes the fitting errors for T1 and T2 for the original and the calibrated IR-TrueFISP validation data sets. Figure 1 shows T1 and T2 maps from an imaging slice of one of the validation data sets.

	IR-TrueFISP data set	Fitting error [mean (std)]
T1	Original	0.18 (0.22)
	Calibrated	0.08 (0.21)
T2	Original	0.32 (0.60)
	Calibrated	0.02 (0.37)

Table 1: Fitting errors of the original and the calibrated IR-TrueFISP validation data sets.

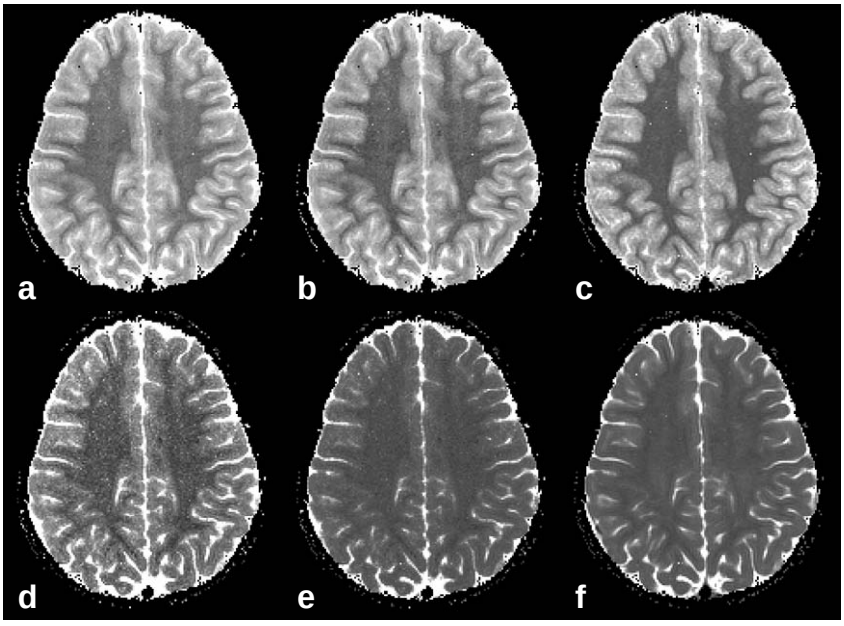

Figure 1: Quantitative maps from a validation data set (a) T1 map directly generated with IR-TrueFISP, (b) corrected IR-TrueFISP T1 map, (c) T1 map generated with reference method, (d) IR-TrueFISP T2 map (e) corrected IR-TrueFISP T2 map, and (f) T2 map of reference method.

Discussion: In this study we examined whether IR-TrueFISP can produce accurate quantitative T1 and T2 values by calibrating it with an established standard quantification method. We were able to create a calibration function that transforms the IR-TrueFISP such that the fitting error between the conventional data and the IR-TrueFISP data became very small and showed almost no bias, especially for the T2 values. This is also reflected in the quantitative maps: the calibrated T2 map (fig 1e) very closely resembles the T2 map of the reference method (fig 1f).
The calibration function was obtained from patient data which has the benefit that the function is very well defined for physiological relevant T1 and T2 values. Data was acquired over a relatively large cohort over a long period of time, which makes the model less sensitive to short term influences (scanner calibration status, shim, etc.) and therefore more globally applicable.

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