A new Model-Based Technique for Accurate Reconstruction of T_2 Relaxation Maps from Fast Spin-Echo Data

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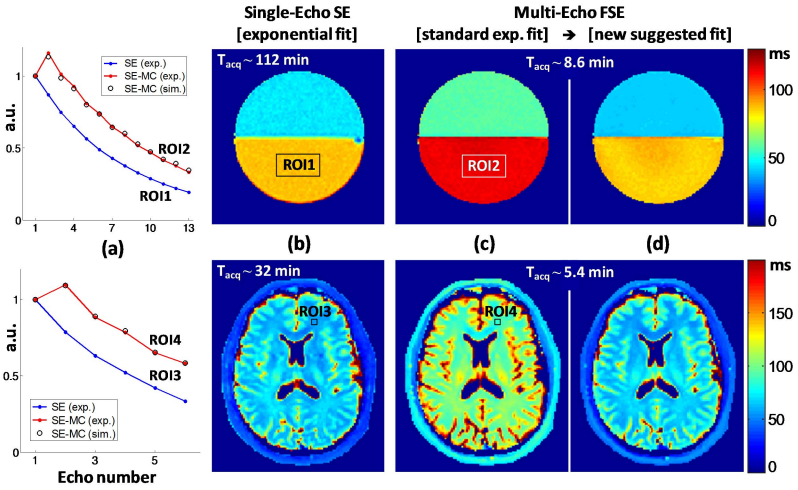
Introduction T_2 contrast is one of the most commonly used tools for non-invasive diagnosis and prognosis of pathologies. Although T_2 assessment is usually done in a visually-qualitative manner, its quantitative characterization holds valuable information for numerous applications, including the detection of biochemical and biophysical changes in hip and knee cartilage [1,2,3], diagnosis of prostate and liver cancer [4,5], assessment of diseased and post-transplant myocardial edema [6], and the investigation of muscle physiology [7]. Genuine quantification of T_2 however, remains challenging in clinical practice due to the very long scan times associated with full spin-echo (**SE**) acquisitions (10s min), or, in the case of multi-echo fast SE sequences (**FSE**), due to an inherent bias of T_2 values resulting from contamination of the echo-train by stimulated and indirect echoes (Fig. 1a). In addition, most fast methods are sensitive to B_0 and B_1 inhomogeneities, non rectangular slice profiles, and spurious diffusion weighting. Several approaches have recently been proposed for overcoming these artifacts by employing analytical or numerical stepwise tracing of all coherence pathways arising in a multi-echo sequence [8,9,10]. These methods show promising preliminary results, yet, entail high numerical complexity, do not always account for all experimental factors, or do not allow straightforward deduction a T_2 value given an arbitrary train of echoes. In this work we present a new technique for post-processing FSE-based T_2-maps, relying on full Bloch simulations of the experimental pulse sequence. The technique enables accurate modeling of all coherence pathways and furthermore allows the incorporation of any experimental factor such as RF pulse shapes, spin diffusion, B_0 and B_1 non-uniformities, and multi-exponential T_2 distributions.

Methods Preparation stage [≈minutes]: Full Bloch simulation (implemented in-house in MATLAB and C++) of the prospective FSE pulse sequence was performed on a standard PC, using the exact RF pulse shapes, echo train length (**ETL**), and other experimental parameters. Simulations were repeated for a range of T_2 values (T_2=1…500ms ΔT_2=1ms), producing a set of echo-modulation-curves, each associated with a unique T_2 value. Data acquisition: Data was acquired on a 3T whole-body Siemens scanner for: **1)** two-compartment phantom, **2)** *in vivo* human brain, and **3)** *in vivo* human prostate (*not shown*), using full SE and multi-echo FSE sequences, employing identical parameters {*Phantom*: TR=4sec, TE=[12…156]ms, N_{TEs}=13, ETL=1 for SE and 13 for FSE, res=1.25x1.25 mm^2, slice=3mm, T_{acq}=112min for SE and =8.6min for FSE}; {*Brain*: TR=3sec, TE=[20…120]ms, N_{TEs}=6, ETL=1 for SE and 6 for FSE, res=1.7x1.7mm^2, slice=3mm, T_{acq}= 32min for SE and =5.4min for FSE}. Post processing [≈sec]: T_2 maps were generated using **(i)** gold-standard exponential fit of the SE set of images, **(ii)** similar exponential fit of FSE data, and **(iii)** [proposed method:] fitting of FSE data via minimization of the L2 norm of the difference between experimental and pre-calculated echo-modulation-curves.

Results Fig. 1 shows two examples of T_2 maps, generated using the proposed technique. **(a)** Experimental echo-modulation decay curves for SE (blue), and FSE (red), corresponding to panels (b) and (c) respectively, demonstrating the strong effect of stimulated echoes, in multi-echo sequences. Bloch simulations are able to very accurately predict this effect (black circles). **(b)** T_2 maps generated using gold-standard SE sequence data. **(c)** FSE based T_2 maps using similar exponential fit. **(d)** Same data as in (c) but employing best L2 norm fit to the pre-calculated set of echo-modulation-curves. Juxtaposing panels (c) & (d) vs. the gold-standard T_2 maps in (a), a consistent improvement in T_2 accuracy is achieved using the proposed method (panels (d)) for both phantom (avg. error reduced from 32% to 6%) and for brain (avg. error reduced from 70% to 17%) vs. standard exponential fit (panels (c)).



Discussion The proposed technique offers an accurate tool for fast T_2 mapping, which avoids the common penalties associated with multi-echo sequences. By modulating the effect of stimulated- and indirect-echoes a significantly improved fitting accuracy is achieved, yielding T_2 maps with high correlation to those acquired using single-echo SE sequences. This promises reliable T_2 mapping in clinically feasible scan times, with reduced motion sensitivity compared to SE-based approaches. The technique is time efficient, uses no a priori assumptions, and provides a comprehensive and easy-to-use framework that can be further used for modeling other types of spin interactions (e.g., diffusion, $T_{1\rho}$, T_2^*) and acquisition schemes.

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