mISIS-CPMG: a Method for Localized Multicomponent T2 Measurement Immune to Very Short T2 Relaxation Effects

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Introduction: Skeletal muscle T2, as obtained from a mono-exponential decay is a sensitive but non specific indicator of muscle activation or of disease activity. When long echo trains are acquired at high sampling rate, a T2 spectrum can be calculated. In the skeletal muscle, it reveals at least four compartments, with T2 values ranging from 1 to 200 ms, which have been assigned to macromolecules, intracellular, non-vascular extracellular and vascular spaces fractions [1]. It can be reasonably hypothesized that changes in spectrum of muscle T2 will, to some extent, reflect the underlying mechanism and will give some specificity to T2 measurements. Methods for multi-component T_2 measurement which combine single voxel selection (SVS) techniques with the Carr-Purcell-Meiboom-Gill (CPMG) sequence exist but give fairly accurate results only for components with long enough T_2 values (>10 ms) [1,2]. Fast spin-spin relaxation perturbs the response of shorter T_2 components to RF pulses [3]. This leads to unreliable localization and quantification results. The purpose of this study was to develop a method for multi-component T_2 measurement immune to relaxation effects for $T_2 \geq 1$ ms. Image selected in vivo spectroscopy (ISIS) [4] stands out among other SVS methods as offering accurate cuboidal voxel selection independently of pulse flip angle. This offers the possibility of an optimization based on the applied RF pulses. The goal was to optimize ISIS by substituting the usual adiabatic inversion RF pulse by a very short partial inversion pulse with a large bandwidth (BW), capable of obtaining identical responses from all T_2 components to be measured, at the cost of smaller SNR.

Materials and Methods: The selection BW of Quadratic Phase (QP) pulses may be controlled independently of B_1 amplitude. Adiabatic pulses, usually used in ISIS, present an approximately quadratic phase modulation but the condition for adiabaticity imposes limits on minimum pulse duration. Non-adiabatic QP RF pulses, which do not present the same duration constraints, were designed using the Shinnar-Le Roux (SLR) algorithm [6] to achieve high selectivity and broad BW. In this work, QP-RF pulses were optimized and the magnetization response of both very short and long T_2 species was simulated from Bloch equations with MATLAB (The Mathworks, Inc.). A home-made ISIS-CPMG sequence (Fig. 1) and its optimized version, mISIS-CPMG (modified ISIS-CPMG), were implemented on a 3T whole-body scanner (Tim Trio, Siemens Healthcare). Radio Frequency pulse transmission and detection was performed with a circularly polarized transceiver coil (CP Extremity, Siemens Healthcare). Experimental slice profile of the designed QP pulse was measured over two 1 liter-phantoms with T_2 values of 2 ms and 100 ms, in separate experiments. The mISIS-CPMG and the conventional ISIS-CPMG with an adiabatic Hyperbolic Secant (HS) pulse were applied for T_2 quantification of a 300 mL rectangular volume containing three 50 mL phantoms of 4.8, 0.26 and 0.11 mM $MnCl_2$ solutions, corresponding to T_2's of 2, 36 and 83 ms and T_1's of 26, 485 and 960 ms, respectively. The excitation and refocusing pulses in the CPMG were 200 and 400 µs long, short enough to avoid relaxation effects. In both protocols, the applied echo-spacing was 1.5 ms, and 300 echos were acquired; repetition time (TR=10s) was long enough to guarantee full T_1 relaxation. Total acquisition lasted 160 s. Multi T2 deconvolution was performed by regularized minimum least squares fitting [5].

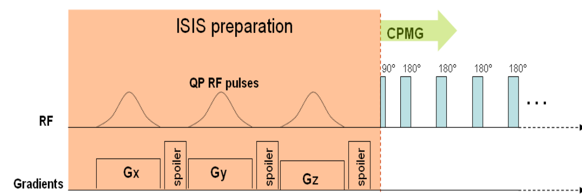

Figure 1: RF and Gradients pulse sequence for the ISIS-CPMG method

Results: The designed QP RF pulse was 1.7 ms long, with BW = 10 kHz and B_{1peak} = 31 µT (Figure 2). The simulated slice profiles obtained with this pulse were virtually identical for short and long T2 components (Figure 3). The immunity of the designed pulse to transverse relaxation effects was confirmed experimentally (Figure 4). Figure 5 presents the T2 decay curve obtained from the 3 phantoms with the mISIS-CPMG sequence. In Figure 6, T_2 spectra, obtained with the conventional and modified versions of ISIS-CPMG are compared. Playing ISIS-CPMG with an adiabatic 5 ms long HS pulse resulted in an underestimation of shorter T_2 components of 20%, which was almost completely prevented by the insertion of the shorter QP pulse.

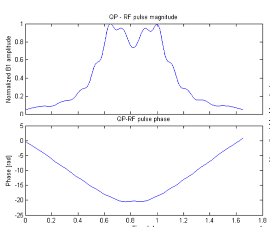

Figure 2: Magnitude and phase of the designed QP RF pulse.

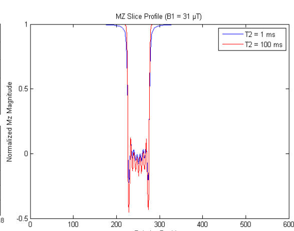

Figure 3: Simulated Mz responses of short and long T2 components to the designed QP pulse.

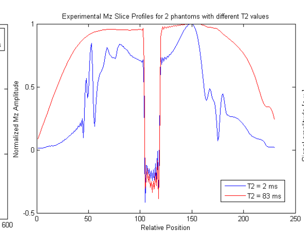

Figure 4: Normalized Experimental Mz responses of two phantoms of different T2 to the designed QP pulse.

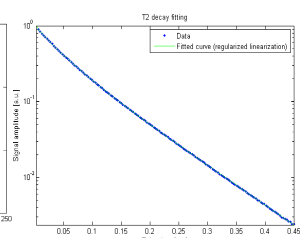

Figure 5: T2 decay of the three 50 mL phantoms measured with the mISIS-CPMG

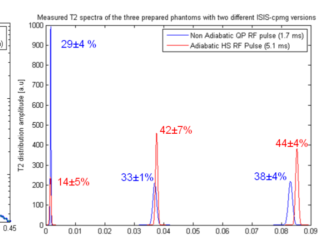

Figure 6: T_2 spectra obtained from both versions of ISIS-CPMG.

Conclusion: QP RF pulses can be optimized to obtain adequate excitation of short T2 components and guarantee identical efficacy and spatial selectivity of magnetization responses over a large range of T2s.

When implemented with these pulses, mISIS-CPMG allows localized multi-component T2 measurement for T2s as short as 1ms and will thus give access to more complete and reliable T_2 spectra, which are expected to be of great interest in evaluation of healthy and diseased skeletal muscle.

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