Simultaneous T_2 and Lipid Quantitation using IDEAL-CPMG

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Introduction. The separation and quantification of co-localized water and fat signals is important in a wide range of pathologies. For example, concurrent muscle damage, inflammation, and fat infiltration are common in neuromuscular diseases. The T_2 of water, $T_{2,w}$, in skeletal muscle lengthens with both myocellular damage and edematous inflammation. However, fatty infiltration prevents accurate $T_{2,w}$ quantitation as the longer T_2 of fat, $T_{2,f}$, masks underlying changes in the water component. Fat suppression techniques can be inconsistent across the imaging volume and remove valuable physiological fat information. We present here a new method, IDEAL-CPMG, that combines iterative decomposition of water and fat with echo asymmetry and least-squares estimation (IDEAL) [1] with a Carr-Purcell-Meiboom-Gill (CPMG) imaging sequence [2]. IDEAL-CPMG results in a series of fat and water images with multiple T2-weightings, enabling measurement of $T_{2,w}$, and $T_{2,f}$ from the fat and water isolated signals along with a T_2-corrected fat fraction.

Methods. A CPMG sequence with N_{TE} refocusing pulses was modified to collect N_φ gradient echoes about each spin echo to produce fat-water phase shifts for use in IDEAL-CPMG decomposition. The IDEAL decomposition as described by Reeder et al. [1] was modified to simultaneously solve for the field map, fat images, and water images using all N_φ phase shifts for all N_{TE} T_2-weightings. For each pixel, the complex measured signal $s_m[n](m=1\ldots N_\varphi, n=1\ldots N_{TE})$ can be defined as $s_m[n]=[\rho_w[n]+\rho_w[n]\exp(i2\pi\Delta f_{fw}t_m)]\exp(i2\pi\psi t_m)$ where $\rho_w[n]$ and $\rho_f[n]$ are the T_2-weighted complex water and fat signals, Δf_{fw} is the fat-water frequency shift, ψ is the field off-resonance, and t_m is the time shift relative to the formation of the spin echo. IDEAL decomposition could be performed independently for each group of N_φ echoes. However, as the off-resonance term is independent of n, the IDEAL-CPMG decomposition is formulated with $2N_{TE}+1$ unknown values and $2N_{TE}N_\varphi$ known values and performed simultaneously over all echoes, thereby improving the estimate of the field off-resonance term. To account for the decreased SNR in measurements at later echo times, a weighted least squares approach was used to weight the solution by the signal magnitude. IDEAL-CPMG decomposition results in a water isolated T_2 decay curve, $\rho_w[n]$, and a fat isolated T_2 decay curve, $\rho_f[n]$. A least squares curve fitting was used to solve for $T_{2,w}$ and $T_{2,f}$, along with the apparent proton densities for water, $\rho_{0,w}$, and fat, $\rho_{0,f}$. Using the apparent proton densities, a T_2-compensated fat fraction, *FF'*, can be calculated according to $FF'=\rho_{0,f}/(\rho_{0,f}+\rho_{0,w})$.

Table 1. Fat fraction percentages in dairy cream phantoms measured using MRS and IDEAL-CPMG.

	Cream 1	Cream 2	Cream 3
MRS	4.7±0.5	11.9±0.6	23.9±0.9
IDEAL-CPMG	6.4±0.7	13.1±1.0	25.8±1.6

Table 2. T_2 relaxation times (ms) in healthy volunteers measured using IDEAL-CPMG and literature values.

	Muscle	Subcutaneous Fat
Gold et al. [3]	31.7±1.9	133±4.4
IDEAL-CPMG	30.7±1.4 ($T_{2,w}$)	141±5.0 ($T_{2,f}$)

IDEAL-CPMG was performed at 3T (Magnetom Verio and Trio, Siemens Medical Solutions, Erlangen, Germany) with N_φ=3 phase shifts (-5π/6,π/2,11π/6) and N_{TE}=16 with a spin-echo-spacing of 10ms. Eight 5mm slices were acquired with a 5s TR and 2.5mm resolution. Fat fraction was determined in three dairy cream phantoms of increasing fat concentrations by spectroscopy and, to match echo-times, the second echo of IDEAL-CPMG. The sequence was then tested in the thighs of five healthy subjects and one patient with the representative muscle disease inclusion body myositis (IBM). All values are reported as mean ± SD.

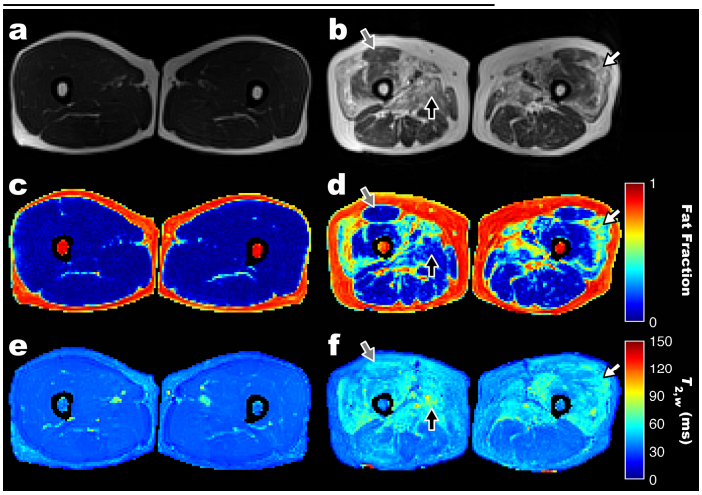

Fig. 1. IDEAL-CPMG results in a healthy volunteer (a,c,e) and a patient with IBM (b,d,f) showing T_2-weighted images (a,b), T_2-corrected fat fraction maps *FF'* (c,d), and $T_{2,w}$ maps (e,f). Differing degrees of edema and fat infiltration can be observed in the various muscle groups in the patient with IBM (right) versus the control (left). Of note are hyperintense regions in the T_2-weighted image. The use of IDEAL-CPMG allows these regions to be distinguished as only inflammation (black arrow), or fat infiltration and inflammation (white arrow). The slight hyperintensity of the rectus femoris (grey arrow) is more easily appreciable on the $T_{2,w}$ image, and is found to be inflammation rather than fat infiltration.

Results. Excellent agreement was found between the fat fraction measured using MRS and IDEAL-CPMG in the dairy phantoms as shown in Table 1. In the healthy volunteers, agreement with the literature was found for the relaxation times in subcutaneous fat and rectus femoris muscle (RF) as shown in Table 2. Across all volunteers, the *FF'* in the RF was 3.9±0.5%, while in the subcutaneous fat the *FF'* was 86.2±1.9%. In Fig. 1 IDEAL-CPMG results are shown for a representative healthy volunteer and patient with IBM. In contrast to the healthy volunteer, regional fat infiltration and/or inflammation are apparent in the IBM patient.

Conclusions. The IDEAL-CPMG approach was able to differentiate fat and water components at each acquired echo time, allowing T_2 mapping of each species independently in phantoms and *in vivo*. The ability of IDEAL-CPMG to quantitatively differentiate local changes in edema from fat infiltration may prove to be an invaluable method in the evaluation of neuromuscular diseases and in unambiguously quantifying $T_{2,w}$ and the T_2-corrected fat fraction as potential markers of disease.

References. [1] Reeder et al., MRM 2005;54:636-44, [2] Mulkern et al., MRM 1990;16:67-79, [3] Gold et al. AJR 2004;183:343-51