T1 Effect in Fat Quantification Errors in RF Saturation and IDEAL Gradient Echo Imaging

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Introduction Quantification of fat content using MRI provides important information for clinical diagnosis such as in hepatic steatosis [1]. Several groups have used different MRI imaging techniques to estimate liver fat content including spectroscopic approach [2], opposed-phase imaging [2,3], RF saturation [1,3] and three-point Dixon IDEAL (iterative decomposition of water and fat with echo asymmetry and least-squares estimation) [2]. However, tissue relaxation, in particular T1, is a potential source of bias in fat quantification unless corrections are performed [4]. In this experimental work using phantoms with long and short T1 values, we report the quantitative influences of the T1 effect on fat quantification when using RF saturation and IDEAL methods.

Materials and Methods On RF saturation measurements, the fat-fraction was computed from MR images with and without fat-saturation according to the definition of fat fraction and water fraction as $f_{fat-RF} = (1-I_{fat-sat}/I_{non-sat})$ (1) and $f_{water-RF} = I_{fat-sat}/I_{non-sat}$ (2), where $I_{fat-sat}$ and $I_{non-sat}$ are signal intensities with and without fat saturation, respectively. For IDEAL, complex data acquired from gradient echo at different TEs were reconstructed separately for fat and water images according to the original IDEAL algorithm for multi-coil data acquisition [5]. From the calculated fat and water images the fat-fraction was obtained as, $f_{fat-IDEAL} = I_{fat} /(I_{fat} + I_{water})$ (3) and $f_{fat-IDEAL} = I_{waert} /(I_{fat} + I_{water})$ (4), where I_{fat} and I_{water} are intensities of the fat-only and water-only images. Note that relaxation effects were included in none of these formulas.The fat/water signal behavior at a given TR or flip angle in different sequences were computed according to $S_{sub} = Mo_{sub} (1-exp(-TR/T1_{sub}))$ for FSE and according to $S_{sub} = Mo_{sub} (1-exp(-TR/T1_{sub}))*sin\alpha/(1-exp(-TR/T1_{sub})cos\alpha)$ for SPGR, respectively, where the subscript "sub" represents fat or water substance. The true fat fraction was therefore $Mo_{fat}/(Mo_{water}+Mo_{fat})$, against which the measured fat faction $S_{fat}/(S_{water}+S_{fat})$ from experiments were compared.

Two phantoms, each with 9 20-mL glass tubes containing different fractions of fat-water mixtures immersed in a 12.5x12.5 cm^2 square plastic container, were used to experimentally evaluate the fat fraction measurement errors using selective saturation and IDEAL fat-water separation method. The nine tubes in both phantoms equally consisted of 0%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 100% fat concentrations by mixing different volume of oil with water. Pure water was used in one phantom, while aqueous solution of MnCl$_2$ (0.1mM) was used in the other. The T1/T2 values of pure water, water doped with MnCl$_2$, and oil were about 2000/500ms, 950/100ms, and 250/60 ms, respectively. Five imaging sequences were tested on a 1.5T MRI scanner (Signa HDx, GE) using an 8-channel head coil: FSE-T1-weighted images *with* and *without* fat-sat (TE/TR=11.68/700ms, ETL=3, slice thickness=60mm), FSE-PD-weighted images *with* and *without* fat-sat (TE/TR=11.68/4000ms, ETL=8, slice thickness=60mm), and 3D FSPGR IDEAL (TE=1.87/3.43/4.99ms, TR=10ms, flip angle=10˚, slab thickness 60mm). All sequences used 1 NEX, 256x256 matrix size and 18cm FOV. Data post-processing and analysis programs were implemented using Matlab 7.0 on a personal computer.

Results The experiment data versus true fat fractions using FSE-T1, FSE-PD, and SPGR were shown in Figs.1a & 1b for the short and long T1 phantoms, respectively. The solid lines with different colors represented the computed bias in fat fraction measurements in each sequence, showing good agreement with the experimental measurements. The maximum bias for the short-T1 phantom was 12.1% for FSE-T1, 0.37% for FSE-PD and 6.7% for SPGR, respectively, and were much higher in the long-T1 phantom (23.2% for FSE-T1, 1.3% for FSE-PD, and 17.8% for SPGR, respectively). Figs.1c, 1d, 1g, & 1h showed, respectively, FSE-PD image with fat-sat, without fat-sat, IDEAL water image, & IDEAL fat image from the short-T1 phantom. The fat-fraction maps (Figs.1e & 1i) determined from RF saturation & IDEAL method using Eqs.(1,3) and water fraction maps (Figs.1f & 1j) determined from RF saturation & IDEAL method using Eqs.(2,4) were also demonstrated.

Discussion & Conclusion Our results suggest fat-fraction measurement is affected by the T1 value of the tissue in a nonlinear manner, with larger bias encountered in long-T1 than short-T1 tissues. While T1 relaxation is an obvious factor that could influence accuracy in fat quantification, previous studies seldom considered the T1 effects [3]. The results from our study show that the T1 bias in fat-fraction measurements depends on scan parameters (T1 or PD) and sequences (FSE vs. GRE), with PD-weighted images better immune to T1 biasing errors. In clinical situations where relaxation parameters may alter pathologically, therefore, T1 effects should be included in fat-fraction quantification using RF saturation and IDEAL.

Reference
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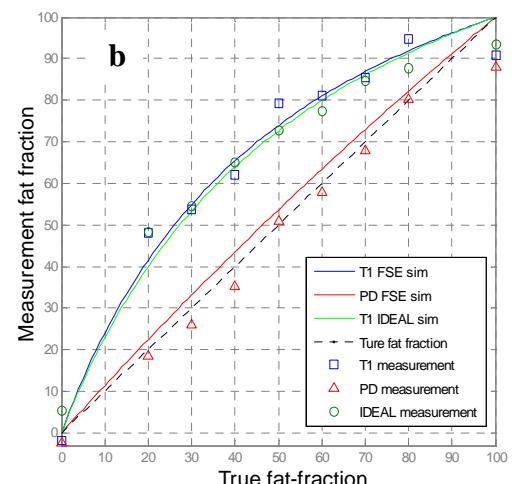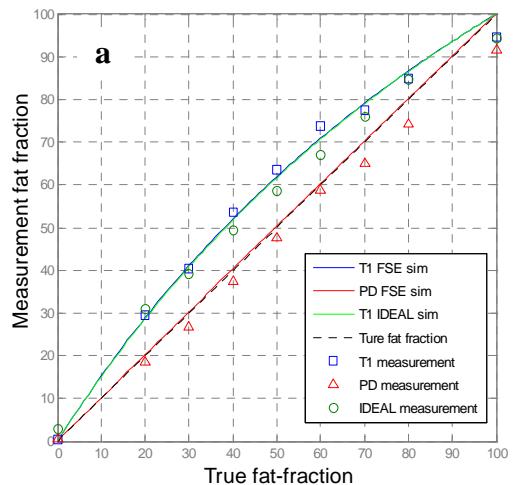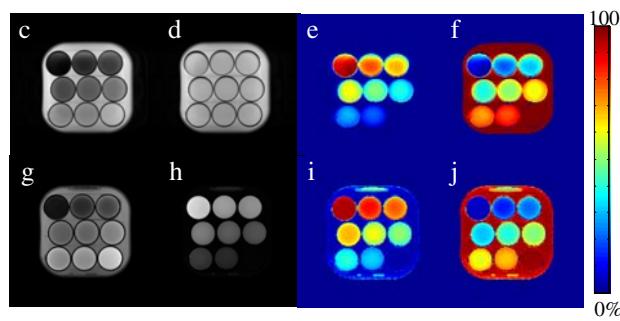
Figure 1. (Right) T1 bias calculated (solid lines) and measured (markers) for short-T1 (a) and long-T1 (b) phantoms, showing good agreement. (Left) Images acquired for the short-T1 phantom with FSE-PD fat-sat (c), FSE-PD without fat-sat (d), IDEAL water image (g), & IDEAL fat image (h), alone with fat fraction maps determined from RF saturation (e) & IDEAL method (f) and water fraction maps determined from RF saturation (f) & IDEAL method (j) suggest that T1 correction is needed for accurate fat-fraction measurements.