Apparent Change in the T1 of Lipids in Mixture

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Introduction – Fat quantification using chemical-shift fat-water MRI is common in studies of hepatic steatosis and obesity. With methods like IDEAL [1], a fat-water signal fraction is typically computed on a voxel-by-voxel basis as $F/(F+W)$, where F and W are the decomposed fat and water signals, respectively. In order for the signal fraction to accurately represent the underlying fat content, several works have shown that it is important to consider a multi-peak rather than a single-peak spectral model for fat [2] and T1-bias between F and W signals [3]. To minimize T1-bias, the use of small flip angles (≈ 5°) in IDEAL gradient-echo (GRE) has been suggested [3]. In addition to the fat-water signal fraction, a fat-only signal fraction (F/F_{PURE}) has also been used in fat quantification, where F_{PURE} is the signal from a voxel containing pure fat [4]. This work describes the apparent change in the T1 spin-lattice relaxation of fat and water from their pure, natural T1 values when present in relatively homogeneous mixtures. Thus, F/F_{PURE} is also susceptible to T1-bias. Phantom and *in vivo* results are presented that suggest this apparent T1 bias.

Methods and Results – Experiments were performed on a GE 3T scanner using a single-channel head coil (phantoms) or an eight-element torso array (*in vivo*). Multi-peak IDEAL was used to decompose fat and water [2]. T1 measurements were then made on the separated fat and water signals voxel-by-voxel using the DESPOT1 approach [5], where multiple spoiled-gradient-echo images are acquired using a sweep of flip angles with constant TR. Since DESPOT1 depends on accurate knowledge of the actual flip angles, $B1^+$ mapping based on the double-angle-method (DAM) was also utilized [6]. Imaging parameters were: 3D-spoiled-GRE, FOV = 20-22 (phantom) and 40 cm (*in vivo*), 160×160 sampling matrix, 3 mm slices, TR = 50 ms, BW = ±125 kHz, TE = [2.0, 2.55, 3.1, 3.65] ms, flip angle = 5° to 50°, and 50 dummy repetitions. The TR for DAM was 4s. T1 measurements were made in vegetable oil-water emulsions, in ground pork meat, and in the thighs of a volunteer.

- ***Phantom*** – Fig. 1 shows results from the phantom setup. A fat-water signal fraction map (flip = 5°) is shown in the inset of Fig. 1a. The apparent $T1_{FAT}$ and $T1_{WATER}$ are plotted as a function of the measured fat-water signal fractions in Fig. 1a and 1b, respectively. Note that pure water has a T1 of 2.6 s, and that of pure oil is 250 ms. As the fat content decreases (leftwards in Fig. 1a), $T1_{FAT}$ begins to vary from its pure value, and exhibits a large deviation when water becomes the dominant specie (< 40% fat-water signal fraction). In contrast, as the water content decreases (rightwards in Fig. 1b), $T1_{WATER}$ gradually decreases from its pure value. In this example, the apparent $T1_{FAT}$ changed more than three-fold across the fat-water signal fraction spectrum (250 to 911 ms); the apparent $T1_{WATER}$ was halved (2.6 to 1.3 s).
- ***Ground Pork*** – In Fig. 2a (inset), the store-bought ground pork contains visible chunks of pure fat. In Fig. 2b (inset), the pork has been further homogenized in a blender. The $T1_{FAT}$ histograms across the two sample show different distributions. In the chunky sample in Fig. 2a, the T1 distribution is prominent near 300-400 ms, the T1 range of pure fat at 3T. These arise expectedly from the discrete fat pieces. In contrast in Fig. 2b, the $T1_{FAT}$ distribution is prominent between 600-900 ms for the homogenized sample, and there is a noticeable absence of $T1_{FAT}$ distribution at its pure value. The fat-signal fraction of the homogenized sample is ≈ 25%. Note that in the chunky sample in Fig. 2a, there is also an evident distribution of $T1_{FAT}$ about 600-900 ms, which corresponds to fat that is already in mixture with lean tissue.
- ***In vivo*** – Fig. 3a shows a fat image (flip = 5°) of the upper thigh and the corresponding fat-water signal fraction map. The same color bar from Fig. 1a is used. T1 measurements were made in subcutaneous adipose tissue (red ROI #1) and visible intramuscular fat (ROI #2 (blue arrows) and #3 (green arrows)). These regions had fat-water signal fraction ranges of 90-93%, 40-60%, and 15-25%, respectively. Figure 3b plots spoiled-GRE measured and fitted data from the IDEAL-reconstructed fat images as a function of actual flip angle in the three regions. The data for ROI #3 (green) has been amplified by three-fold to make the curvature visible. Note that the apparent $T1_{FAT}$ increases from 280 ms in pure subcutaneous fat to around 600 ms in more-diffused intramuscular fat.

Conclusion – We have demonstrated in three separate scenarios the increase in apparent $T1_{FAT}$ when fat is in relatively homogenous mixture with water and lean tissues. The effect is significant when the fat-water signal fraction is < 40%. The emulsion phantom results from this work bears similarity to a previous study [7]. We suspect the change in $T1_{FAT}$ to be caused by the existence of predominant water in the local molecular lattice surrounding fat spins. With increasing number of *smaller* water spins, it is plausible that the molecular tumbling rate of fat spins increases when in mixture, thus leading to a mismatch with the B0-Larmor frequency. As a result of the mismatch, an *increase* in apparent $T1_{FAT}$ occurs. Conversely, we suspect the tumbling rate of water to be slowed in the presence of *larger* fat molecules. This causes the water tumbling rate to more closely match with the B0-Larmor frequency, thus leading to a *decrease* in apparent $T1_{WATER}$. This T1 phenomenon requires further study, and represents an interesting complexity and factor to consider in fat quantification. It may also have implications in T1-based fat suppression.

[1] Reeder SB, et. al. *JMRI* 25:644-652, 2007. **[2]** Yu H, et al. *MRM* 60:1122-1134, 2008. **[3]** Liu CY, et al. *MRM* 58:354-364, 2007. **[4]** Hu HH, et al. ISMRM 2008, 3794. **[5]** Deoni SCL, et al. *MRM* 49: 515-26, 2003. **[6]** Stollberger R, et al. *MRM* 35:246-251, 1996. **[7]** Poon CS, et al. *MRI* 7:369-382, 1989.

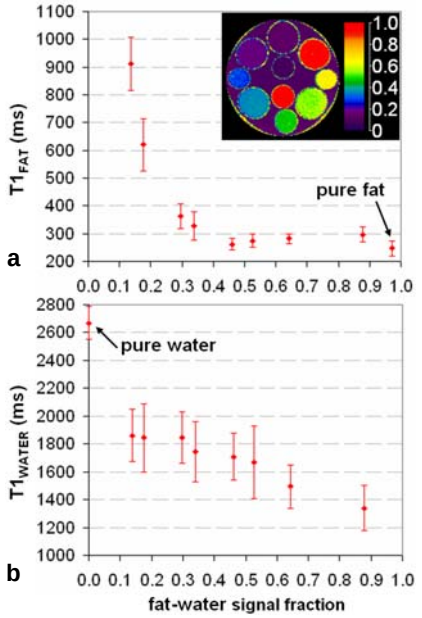

Fig. 1: (a, inset) Fat-water signal fraction of emulsions. Measured apparent T1 of (a) fat and (b) water component for each mixture.

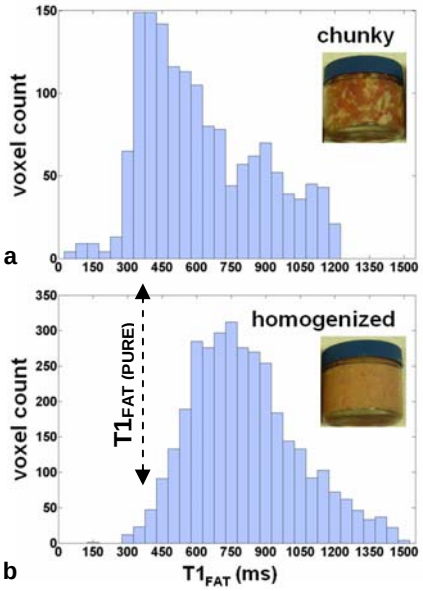

Fig. 2: (a) Chunky and (b) homogenized ground pork exhibit different distributions of $T1_{FAT}$. $T1_{FAT}$ increases (right-shift) in the homogenized sample (25% fat-water signal fraction).

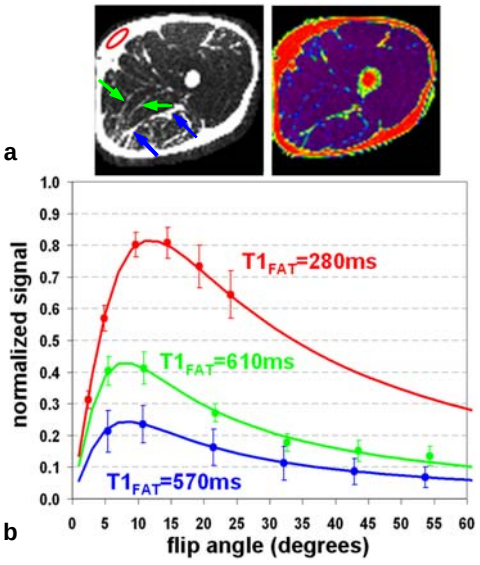

Fig. 3: (a) $T1_{FAT}$ measurements were made in subcutaneous adipose tissue and two regions of visible intramuscular fat with different fat-water signal fractions. (b) Measured data points and fitted spoiled-GRE curves, with estimated apparent $T1_{FAT}$.