On the confounding effect of temperature on chemical shift-encoded fat quantification

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Target Audience: Researchers interested in fat quantification techniques and applications.

Purpose: The proton resonance frequency (PRF) of water depends on temperature, whereas the PRF of triglycerides is temperature independent (aside from bulk susceptibility effects)[1]. This leads to a temperature dependence of the frequency shift between fat and water resonances, which may introduce errors in chemical shift-encoded (CSE) fat quantification methods that assume a known relative shift between the PRF of water and fat[2]. The purpose of this work is to characterize the confounding effect of temperature on CSE fat quantification, and to evaluate the effectiveness of a temperature-corrected spectral model of fat to avoid these errors.

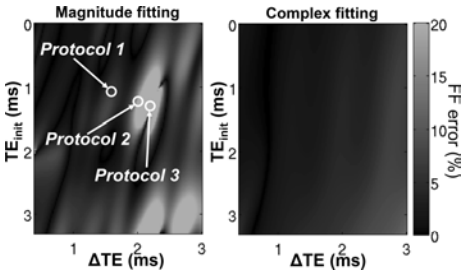

Figure 1: *Temperature-related frequency shifts can result in fat quantification errors. These errors are heavily dependent on acquisition (TE combination), and reconstruction (magnitude or complex fitting). Images show FF errors in simulations where 6-echo signals were generated with fat-water shift 3.69ppm but reconstructed assuming a shift of 3.4ppm.*

Methods: 1) Simulations were performed at 1.5T for CSE fat-water signals at various frequency shifts (to reflect imaging at different temperatures) and echo time combinations to analyze the effects of varying the fat-water frequency shifts on fat quantification. **2)** Oil-water phantoms (fat-fractions=0%,5.3%,10.5%,20.9%,31.2%,41.3%,51.4%,100%) were constructed[3] and scanned using a 1.5T scanner (HDxt, GE Healthcare, Waukesha, WI), in a water bath with temperatures varying between 0-40°C. Data were acquired using single voxel T2-corrected STEAM[4] spectroscopy and CSE imaging[5] at three different 6-echo time (TE) combinations (shown on figure 1). The temperature-dependent fat-water frequency shift was measured using STEAM (FF=50% vial). **3)** An explanted human liver, rejected for transplantation due to steatosis, was scanned using STEAM and CSE imaging (TEinit=1.20ms, ΔTE=1.98ms). Spectroscopy parameters included: TE=10-30ms, TR=3500ms, 2048 readout points, 1 average, and spectral width=±2.5kHz. Fat-water reconstructions were performed using four different techniques: magnitude or complex fitting[6], with standard (frequency shift of 3.4ppm between water and main methylene fat peak) or temperature-corrected (corrected fat-water shift) signal modeling.

Results and Discussion: A linear dependence between temperature and fat-water frequency shift was observed (r^2=0.997, slope=-0.01085±0.00015 ppm/°C), in good agreement with literature values[7] (plot not shown for brevity). In simulations (Figure 1) and phantom experiments (Figure 2), magnitude fitting with standard signal modeling resulted in large fat quantification errors. Errors were largest for echo time combinations near TE_{init}≈1.3ms, ΔTE≈2.2ms. Errors were smaller with complex fitting, and were altogether avoided using a temperature-corrected signal model.

Knowledge of the temperature of the sample being imaged allows for appropriate adjustment of the fat-water frequency shift and is effective at mitigating this potential confounder. However, the SNR performance of magnitude reconstructions is sensitive to the choice of TE combination and to the PRF of water[8]. This dependence should be taken into account when designing a protocol for scanning samples at a known temperature.

Explanted liver results are shown in Figure 3. Note the apparent spatial heterogeneity in fat-fraction maps, particularly in magnitude reconstruction. We speculate that this is due to temperature heterogeneity within the explanted liver (warmer near the edges than the center), due to insufficient time for full warming to room temperature. For this reason, it may be important to use acquisition and reconstruction techniques that are robust to uncertainty in temperature (ie: acquisition: TEs away from TE_{init}≈1.3ms, ΔTE≈2.2ms, reconstruction: complex fitting).

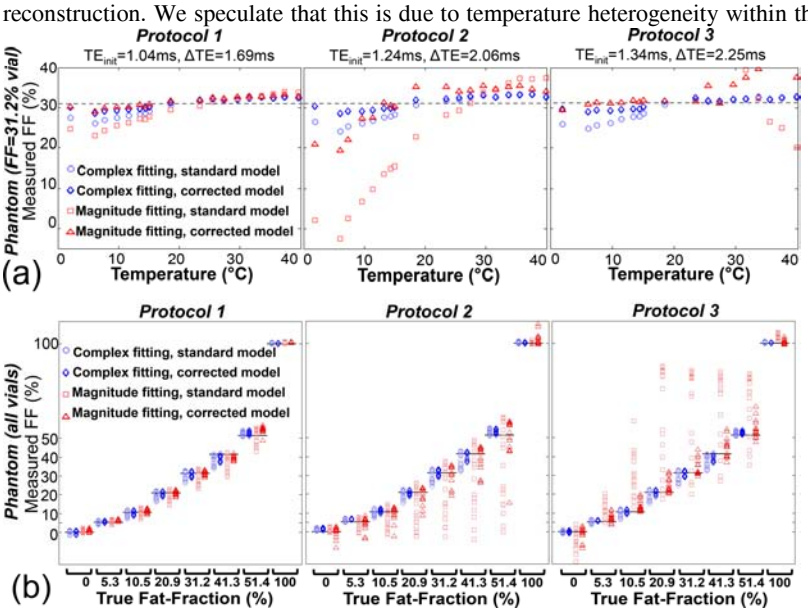

Figure 2: *Phantom results demonstrate the sensitivity of fat quantification to temperature. (a) Explicit temperature dependence (for true FF=31.2%) shows increasing errors for larger temperature offsets relative to body temperature (37° C), in good agreement with simulations. (b) For all phantom vials except FF=0% and FF=100%, standard magnitude fitting results in the largest variability in FF estimates over all temperatures.*

Conclusion: Temperature is a confounding factor for fat quantification. If not accounted for, it can introduce errors in fat quantification in phantom and ex vivo acquisitions.

References: [1]Kuroda K. MRM 1997;38:845-851; [2]Yu H. MRM 2008;60:1122-1134; [3]Hines, JMRI 2009;30:1215-1222.[4]Hamilton G JMRI 2009;30:145-152; [5]Meisamy S. Radiology 2011;258:767-775; [6]Hernando D. MRM 2010;64:811-822; [7]Peters RD. MRM 1998;40:454-459; [8]Hernando D. MRM 2012;67:638-644.

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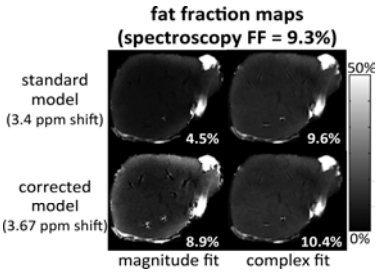

Figure 3: *Explanted liver results, in good agreement with phantom results and simulations. Complex fitting or temperature-corrected spectral modeling improves fat quantification accuracy (MRS used as reference).*