Absolute Temperature imaging with Non-Linear Fat/Water Signal Fitting

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INTRODUCTION

Temperature mapping methods with MRI that are based on the proton resonance frequency shift (PRF) are typically classified into image-based phase fitting and spectroscopic methods, with the latter providing a more accurate measurements at the cost of imaging time or spatial resolution. Previous work has shown improved temperature mapping using fat as an internal reference in spectroscopic imaging in tissues that contain both water and fat [1]. In order to exploit the high spatial resolution of image-based methods we propose an internally reference model based fitting of data that limits the chemically shifted species to known proton groups, such as the multiple peaks of fat and water. This allows effectively spectroscopic measurements for absolute temperature measurement with substantially fewer measurements.

THEORY

The signal at each voxel is described as a sum of contributions from fat and water, each with separate T2* decay constants:

$$S(t) = \left(F \cdot \phi_f(T,t) e^{-t/T2^*_{fat}} + W \cdot \phi_{H_2O}(T,t) e^{-t/T2^*_{H_2O}} \right) \cdot e^{i\psi t}$$

Where F and S are the complex fat and water signals respectively, T is the temperature, and ψ is the off-resonance due to B0 inhomogeneity. φ_f and φ_{H2O} are the temperature dependent signal spectrums, (e.g. $e^{i\Delta f T \cdot t}$ for water, $Ae^{i2\pi(210+\Delta f_A(T))\cdot t} + Be^{i2\pi(159+\Delta f_B(T))\cdot t}$.... for fat). Within a reasonable range of fat/water signal fractions, the temperature can be solved for without directly requiring separate calibration steps. To do so, non-linear fitting must be utilized on a set of sufficiently sampled time points. For all work done here, a modified Newton-Raphson fitting algorithm was used with an L2-Norm line search and Tikhonov regularization. This iterative method is very effective at dealing with the relatively complex nature of the signal model and has approximately linear convergence rate.

METHODS

All imaging was performed on a 1.5T clinical scanner (Excite HD, GE Healthcare, Waukesha, WI). To evaluate the efficacy of our signal model based approach, images were acquired of two containers of heavy whipping cream (35% fat content): one at roughly room temperature and the other starting at roughly 0 °C and allowed to naturally heat up. Images were acquired with a 3D multi-echo gradient echo sequence (echo train length=16, TR=37ms, TE1=1.3ms, ΔTE=2.2ms, BW=781hz/pizel, voxel resolution 1.3x1.3x10mm, α=15°,FOV = 35x17x8cm,single channel head coil). Images were acquired every 3 minutes for 100 min, while temperature readings were recorded with a fiber optic temperature sensor (Model T1, Neoptics, Québec City, Québec) at the start of each scan. Complex images were reconstructed online, transferred offline, and fit to the signal model. For this study, a single frequency peak was used for water while 6 frequencies were used for fat (210,159, -47, 236, 117, 23 Hz). Temperature dependencies were based on [2], with all fat peaks behaving similar to the CH_2(210 Hz) peak. Values were initialized with the IDEAL[3] fat/water solution, and iterated until the change per iteration in all parameters was less than 1e-12.

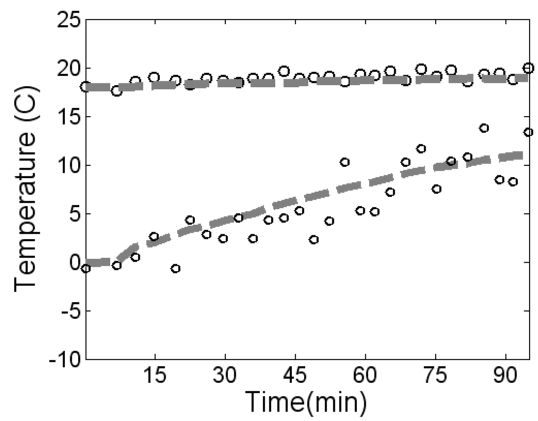

Figure 1 MR Chemical shift measured (circles) and that measured with the probe (dashed lines). Excellent agreement is seen between measurements with MR and the probe.

RESULTS

Representative temperature images are shown in Figure 2, the image shown was acquired 25min after the whipping cream was removed from the cooler. Some variation is seen in the cold water-only image due to partial congealing of the fat, however agreement with the probe measurement is excellent as shown in Figure 1 for a single voxel near the center of the object, roughly 1 cm from the temperature probe.

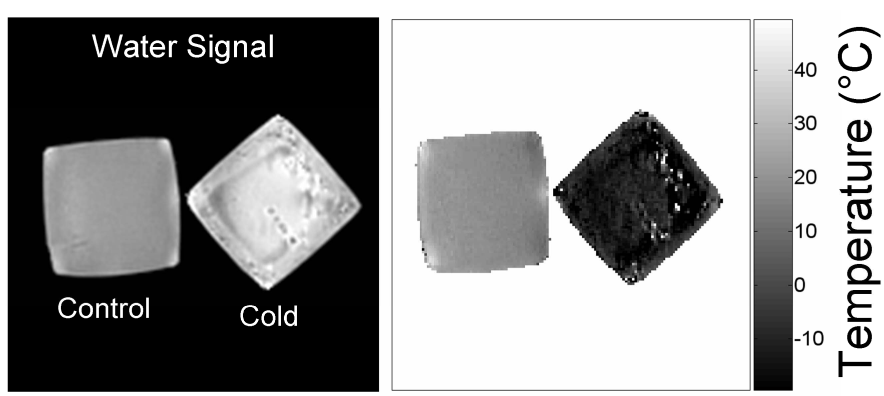

Figure 2. Water signal magnitude for the central slice of the volume at 25min (left) and corresponding temperature map (right). While some variations are seen within cold the volume due to freezing, overall agreement with probe temperatures is excellent.

DISCUSSION

Signal model based temperature imaging with Non-linear based fitting shows great promise for absolute temperature measurements. Accurate measurements were achieved with only 16 TE's, far fewer than that required for spectroscopic imaging. Further accuracy will be realized with improved characterization of the chemical shift with respect to each element.

REFERENCES

1. Kuroda *et al* MRM 43:220-225 2. McDannold *et al* Med Phys 28(3): 346-355 3. Reeder *et al* MRM 51(1):35-45

ACKNOWLEDGEMENTS

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