Fat-Referenced MR Thermometry in Heterogeneous Tissue Using IDEAL

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Introduction: Accurate, stable temperature mapping is needed to safely and successfully treat breast tumors with magnetic resonance guided focused ultrasound surgery [1]. Time-varying, non-temperature dependent field disturbances in the breast may cause significant temperature measurement error when conventional phase difference proton resonance frequency shift (PRFS) thermometry techniques are used [2]. In phantoms or tissues where fat and water are homogeneously distributed, fat signal can be used as an internal reference to correct for phase disturbances [3-5]. However, these methods fail in heterogeneous tissue such as the breast. We have developed a fat-referenced temperature measurement technique that works in heterogeneous tissues, correcting for non-temperature induced phase changes even in pixels where there is no fat.

Methods: The technique uses IDEAL [6] to generate complex fat and complex water images at two different time points. Neglecting temperature dependent susceptibility effects, the phase difference between adjacent water images ($\Delta\phi_w$) and adjacent fat images ($\Delta\phi_f$) are modeled as follows:

$$\Delta\phi_w = \Delta\phi_T + \Delta\phi_b \quad (1) \qquad \Delta\phi_f = \Delta\phi_b \quad (2)$$

where $\Delta\phi_T$ is the temperature dependent phase change and $\Delta\phi_b$ is the non-temperature dependent phase change. If $\Delta\phi_f$ is measureable in all pixels, the temperature dependent phase change can be isolated by subtracting Eq. (2) from Eq. (1). In heterogeneous tissue $\Delta\phi_f$ is unknown in many regions, making isolation of the temperature dependent phase change difficult. If sufficient fat is present near the anatomy of interest and the fat and water signal can be cleanly delineated, then non-temperature dependent phase change can be estimated in all pixels by using a weighted least squares method to fit a second order, spatially-varying polynomial to the phase difference of the fat images. This generated correction map is subtracted from Eq. (1) to remove non-temperature dependent phase changes.

This method was confirmed in an experimental study using a 3T GE MR750 scanner (GEHC, Waukesha, WI). Imaging was performed on a cylindrical (11cm diameter, 12cm length) *ex vivo* porcine tissue sample that was heated to 56 °C, then allowed to cool to room temperature. A single channel head coil was used to acquire images. For each of 28 measurements, three spoiled gradient echo (SPGR) images at equally spaced echo times TE = {11.71ms, 12.50ms, 13.29ms} were acquired using the following scan parameters: TR = 60ms, flip angle = 20°, FOV = 20cm, matrix 128×128, coronal 8mm slice, bandwidth 62.5kHz. Temperature maps were computed using fat-referenced and conventional phase difference PRFS techniques. A temperature probe (Neoptix, Quebec, Canada), marked by the yellow cross in Fig. 1a, was used to verify temperature measurements.

After obtaining written informed consent, imaging without heating was performed on a healthy volunteer. Measurements (using an eight-channel breast coil) were acquired during two separate, fully exhaled breath-holds. No actual temperature change occurred. Temperature maps were computed using both fat-referenced and conventional phase difference PRFS techniques. The same scan parameters as above were used, except for: TR(30ms), flip(17°), FOV(30cm), and axial slice (8mm).

Results and Discussion: Fig. 1 depicts the results from the porcine tissue experiment. The reconstructed IDEAL water and fat magnitude images are shown in Fig. 1a and Fig. 1b respectively. Temperature values over the 4×4 pixel ROI were averaged and compared with the temperature probe measurement (Fig. 1c). Over 196 minutes of temperature monitoring (21.5°C temperature change), the average and maximum deviation between the PRFS and temperature probe measurement was 2.4°C and 4.8°C, respectively. For the fat-referenced approach, the average and maximum deviation was 1.7°C and 3.7°C, respectively. The temperature maps from the volunteer study are shown in Fig. 2. Fig. 2 and Table 1 indicate that the errors in the PRFS temperature map are relatively large, particularly in the left breast (RMSE=15.2°C). The fat-referenced temperature map shows a substantial improvement in that same breast (RMSE=4.2°C).

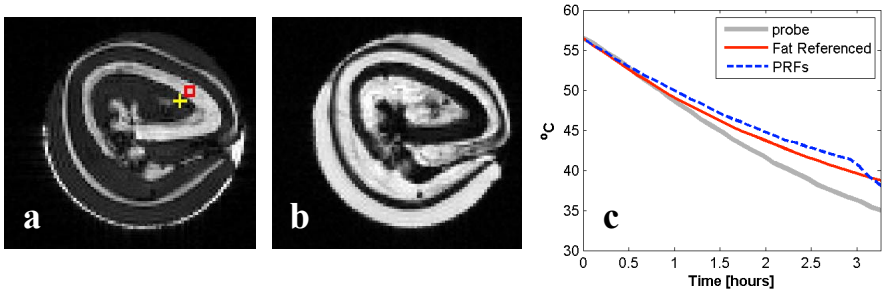

Fig 1. Porcine tissue experiment with (a) water image, and, (b) fat image acquired using IDEAL. Temperature probe (yellow cross), and, MR thermometry readings in ROI (red box) for the two techniques are plotted in (c).

Conclusions: We have demonstrated a fat-referenced temperature mapping technique that corrects for non-temperature dependent, time-varying phase changes in the breast. Temperature mapping errors in the breast were reduced by more than 50% when compared to conventional PRFS techniques (n=1). The *ex vivo* porcine tissue experiment indicated comparable temperature monitoring accuracy to the PRFS technique in a stationary experiment. Further work is needed for accurate thermal monitoring of the breast during free breathing, where non-temperature dependent phase changes may be more significant.

	Left Breast: RMS Error (°C)	Right Breast: RMS Error (°C)
PRFS	15.2	9.0
Fat Referenced	4.2	3.6

Table 1. RMSE values for PRFS and fat-referenced thermometry techniques in breast tissue.

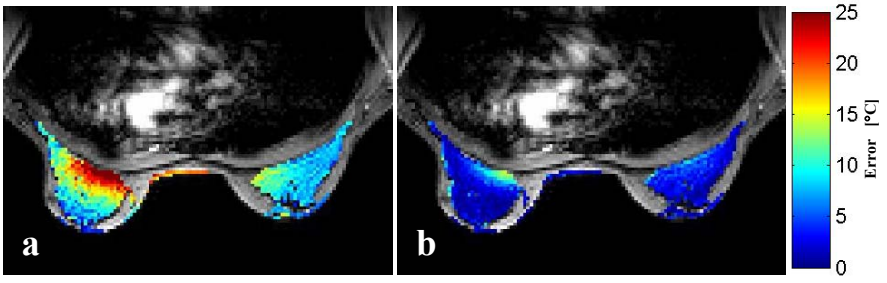

Fig 2. Temperature absolute error maps (°C) for (a) PRFS method, and, (b) fat-referenced method.

References: [1] D Gianfelice et al. Radiology 227:849-855, 2003. [2] N Peters et al. JMRI 29:731-735, 2009. [3] K Kuroda et al. MRM 38:845-851, 1997. [4] A Shmatukha et al. JMRI 25:579-587, 2007. [5] B Soher et al. Proc. ISMRM, 2008. [6] S Reeder et al. MRM 51:35-45, 2004.

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