Correction of errors in PRFS Thermometry due to heat induced susceptibility changes of fat

P. Baron[1], R. Deckers[1], S. M. Sprinkhuizen[1], C. J. Bakker[1], and L. W. Bartels[1]
[1]Image Sciences Institute, University Medical Center Utrecht, Utrecht, Netherlands

INTRODUCTION: In MR-guided high intensity focused ultrasound (MR-HIFU) ablation of tumors in fatty organs, like the human breast, heat induced susceptibility changes of fat may give rise to local field disturbances leading to significant temperature errors inside the tumor as measured by Proton Resonance Frequency Shift (PRFS) thermometry [1]. It is important to note that this problem cannot be solved by applying fat suppression techniques. Here we propose to use T1-based MR Thermometry of fat to calculate the susceptibility changes so as to correct for the errors in PRFS-based MR Thermometry due to the related field disturbances. The feasibility of the proposed method is shown in an oil/water phantom.

1. Use T1 to map temperature in fat (via T1(T))	→	**2.** Calculate local susceptibility changes due to temperature changes in fat (via χ(T))	→	**3.** Use step 2 to calculate field disturbance due to heating in fat. (forward Fourier method)	→	**4.** Correct PRFS MRT maps in water using field disturbance maps from step 3.

Fig. 1. Overview of the steps used in the correction method.

METHODS: Figure 1 shows a schematic outline of the proposed correction method. All MR images were acquired using a 1.5T MRI system (Philips Healthcare). The phantom consisted of a cylinder (diameter=10.8 cm) filled with water with an inner cylinder (diameter=20 mm) filled with sunflower oil. The phantom was allowed to cool slowly from about 60 to 35 °C. During cooling repeated 3D volume dual flip angle spoiled gradient echo scans were acquired for combined PRFS and T1 thermometry. The parameters used were: TE=20 ms, TR=32 ms, FA=13°, 65°, water suppression SPIR, matrix= 64x64x23 , FOV= 128x128x46 mm. The temperature in the water was monitored in two locations (Fig 2a) with a fiber optic probe (Luxtron Corp, Santa Clara, USA). The temperature change in water was calculated by phase subtraction ($\Delta\varphi_{PRFS}$) using the known PRFS shift for water of 0.01 ppm/°C. The T1 of oil was calculated using DESPOT 1 [2]. The T1 temperature coefficient of sunflower oil c_{T1} was calibrated by heating a 50-ml falcon tube of oil in a water bath in steps of 5 °C (range 35-60°) and measuring T1 for each temperature. The PRFS based temperature maps in water were corrected using the local phase change caused by the field disturbances ($\Delta\varphi_d$), which was calculated using a Fourier Transform-based field mapping technique [1,3]:

$$\Delta\varphi_d = \gamma B_0 T_E FT^{-1}\left(\left(\frac{1}{3}-\frac{k_z^2}{k^2}\right)\cdot FT(\Delta\chi)\right) \qquad \Delta\chi = \frac{c_\chi}{c_{T1}}\Delta T_1$$

where c_{T1} (ms/°C) is the T_1 temperature coefficient from the calibration and c_χ the susceptibility temperature coefficient, found in the literature c_χ=0.0055 ppm/°C [1].

The corrected phase change $\Delta\varphi_c$ was then calculated per voxel as follows: $\Delta\varphi_c = \Delta\varphi_{PRFS} - \Delta\varphi_d$ and used for calculating corrected temperature maps.

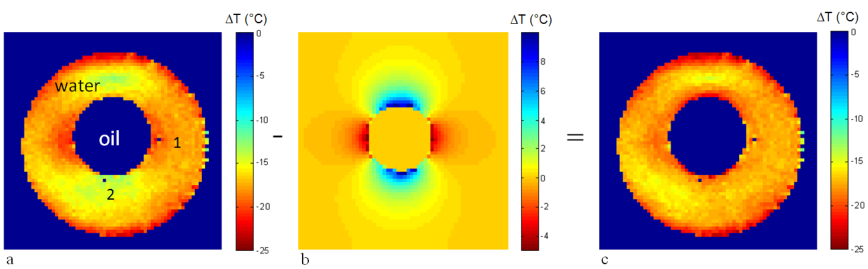

Fig. 2. An example of the correction in an oil/water phantom for a temperature change of about -23°C (a) The PRFS temperature map before correction. (b) The calculated temperature error and (c) the PRFS temperature map after correction.

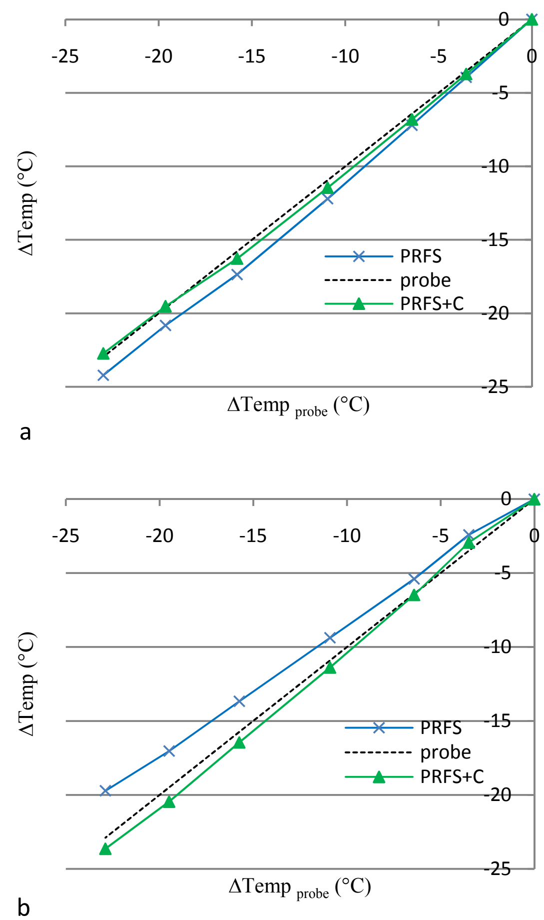

Fig. 3. PRFS-based versus fiber optic probe temperatures corrected (PRFS+C) and uncorrected (PRF) for a) location 1 and b) location 2.

RESULTS: The temperature coefficient of sunflower oil was found to be c_{T1} = 5.0 ms/°C. Figure 2 shows the correction applied for the largest temperature change (ΔT≈ -23°C) during the cooling process. Figure 3 shows temperature changes measured by the PRFS method without correction and after correction compared to the temperature change measured with the fiber optic probes for the two locations in the water indicated in figure 2a. Over the temperature range shown in figure 3, for location 1, the mean/max absolute PRFS error was 0.9/1.6 °C uncorrected and 0.3/0.5 °C corrected (Fig. 3a). For location 2, the mean/max absolute PRFS error was: 1.6/3.2 °C uncorrected and 0.5/1.0 °C corrected (Fig. 3b).

CONCLUSION: The proposed method has been shown to largely correct PRFS thermometry errors caused by heat induced susceptibility changes of fat. For HIFU ablation, fast MR Thermometry of the heated fat region will be needed. Our focus will therefore be on further evaluation of faster implementations of the proposed correction method and application in heterogeneous tissue samples.

REFERENCES: [1] S.M. Sprinkhuizen et al., Magn.Reson.Med.;64(1):239-48, 2010. [2] S.C.L. Deoni et al. Magn. Reson. Med.;49:515-526, 2003. [3] R. Salomir et al. Conc. in Mag Res. Part B: 19(1):26-34, 2003