Feasibility of Temperature Imaging of Fat and Water based on Methylene T1 and Water Proton Resonance Frequency

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INTRODUCTION

Noninvasive temperature imaging of fat is desired for thermal therapies such as high intensity focused ultrasound (HIFU) for breast and other tissue locations with high fat contents. Based on the temperature dependence of T_1 of methylene (CH_2) or methyl (CH_3) protons(1), we have proposed a technique(2) using multiple flip angle(3), multipoint Dixon acquisitions and a least square estimation(4) (5). This technique can be combined with the water temperature imaging technique based on the proton resonance frequency (PRF) shift, because the intra-voxel signal fractions of water and fat protons can be obtained once the proton components are separated. Thus it is possible to combine the PRF-based water temperature map and the T1-based methylene temperature maps. In this paper, feasibility of such an integrated temperature imaging technique is demonstrated.

METHODS

A spoiled gradient recalled acquisition in steady state (SPGR) was designed to evaluate T_1 of CH_2 and/or CH_3. In the first shot, echoes with different TE's were acquired at a certain flip angle (α_1) to obtain real and imaginary parts of water, CH_2 and CH_3 signals based on the multipoint Dixon scheme(4). In the following shots, similar echo sets were obtained with different flip angles. Each data set was reconstructed separately to have the complex water, CH_2 and CH_3 images with different flip angles. The CH_2 image sets were used to obtain T_1 maps, which were then converted to temperature change maps. The complex water images were used to calculate the phase change corresponding to the PRF shift and thus temperature change maps. Then the PRF-based water temperature images and the T_1-based CH_2 temperature images were combined as a weighted sum of the two different temperature maps. Phantom experiments were conducted at 3T (Achieva, Philips) with mayonnaise tubes in a water bath. Temperature in the phantom was monitored with a fiberoptic thermometer (Model 3000, Luxtron). One of the mayonnaise tubes was heated up to around 55 degree, while the other bottles were kept at room temperature (27°C). The following parameters were used; TR, 36 ms, TE, $n \cdot TE_0$ with n = 1, 2, …, 16 and TE_0 = 1.00, 1.05, …, 1.30 ms; number of echoes, 16; flip angles, 20, 50 and 70 degrees; spatial matrix, 128 × 128; SENSE factor, 2. The acquisitions were repeated in the cooling period of the sample. In order to obtain the relationship between T_1 of CH_2 and temperature, inversion-prepared single-voxel PRESS MRS was performed with the following parameters; TR, 12,000 ms; TI, 50, 100, 200, 300, 500, 700, 1000 and 12,000ms; voxel size, 15 × 15 × 15 mm^3.

RESULTS

The proton spectra of the mayonnaise obtained by MRS is shown in Fig. 1. The signal ratio between water, CH_2, CH_3 and other proton components were 1 : 2.13 : 0.102: 0.685 in the particular phantom at room temperature. The temperature coefficient of T_1 of CH_2 was 1.39 %/°C at 30 °C as shown in Fig. 2. The value was close to that obtained in a 11T spectrometer experiments(1). Total time for the 3-flip angle SPGR acquisitions were 6 seconds. Successful separation of the chemical species and calculation of T1's for CH_2 were performed by using the first 5 echoes. Temperature images obtained by the CH_2 T_1 only and by both CH_2 T_1 and water PRF are shown in Fig. 3.

DISCUSSIONS

As a first implementation of the technique, three components model including H_2O, CH_2 and CH_3 were used. The resultant temperature images in the upper row of Fig. 3 exhibited larger error in temperature estimation at higher temperature elevations, partly because of the incomplete setting of the TE values at such temperature range. The error became somewhat smaller when temperature estimation with water PRF was included. The results demonstrated the feasibility of the combined temperature imaging technique based on both methylene T1 and water PRF. Although the fatty acid proton components other than CH_2 and CH_3 were not considered here, it is preferable to include those components. Also, the frequency separations between the signal components can be unknown in order to avoid the signal separation error induce by the incomplete setting of TE's. These optimization(6) procedures are under our current examination.

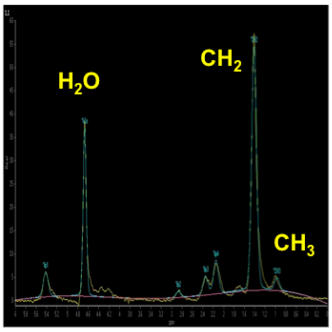

Fig. 1 Typical proton spectra of the mayonnaise sample at 3T.

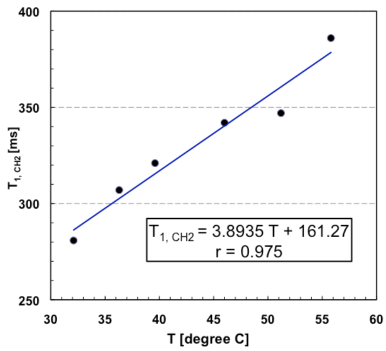

Fig. 2 Relationship between temperature and T_1 of CH_2 obtained by MRS at 3T.

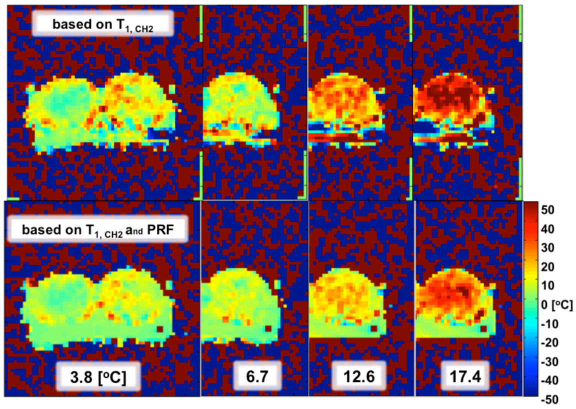

Fig. 3 Temperature elevation maps of the mayonnaise phantom based on T_1 of CH_2 (upper row) and both T_1 of CH_2 and PRF of water (bottom row). Numbers on the labels show the temperature elevation values measured by the optical thermometer.

CONCLUSION

The basic function of the proposed technique with multipoint Dixon and multiple flip angle scheme was demonstrated. The technique can image temperature based on T_1 of CH_2 and PRF of water in 6 second, which seemed to be practical for monitoring temperature in breast under HIFU. Optimization of the echo spacing and component separation process are necessary to improve the accuracy of the measurement.

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