

Temperature Dependence of Relaxation Times in Individual Fatty Acid Components and Its Consideration for MR Thermometry of Adipose Tissues

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INTRODUCTION

Noninvasive MR temperature imaging for breast is desired for thermal therapies such as focused ultrasound surgery to ensure the heat deposition to the target tumor and to protect the surrounding normal tissues. The key issue for breast temperature imaging is to develop a reliable thermometry technique for adipose tissues. Since the previous studies(1,2) were conducted at 0.5-1.5T, the chemical shift components of the fatty acids were not separately observed. In the present study, the temperature dependences of the MR parameters of the fatty acid components were measured in various samples in vitro at 11 T in order to give a reliable basis for quantitative temperature imaging. The effect of coexistence of the different components was examined in numerical simulations.

METHODS(3)

Relaxation time measurements were conducted for olive oil resolved in Chloroform-D with TMS, pure olive oil, mayonnaise, and edible bovine fat in vitro. The bovine samples were taken from different individuals of different producing areas. Each sample was put in a glass capillary of 5mm in diameter, and set in an 11T spectrometer. Sample temperature was set at room temperature and 30-60°C with 10°C steps by using an air blower device. T1 and T2 were measured with traditional IR and CPMG sequences followed by a Marquardt-Levenberg non-linear least mean square algorithm. Eight points of relaxation processes were sampled for the relaxation measurements. After the data were obtained, effect of coexistence of multiple fatty acid components was simulated numerically based on the error propagation theorem. Assuming temperature imaging at 3T, T1 and T2 values at 30°C were set to be 300 and 600 ms. The temperature coefficients of T1 of -CH2- and -CH3 were assumed to be 6 and 12 ms/°C. Then the ratio of these fatty acid components was set at 1 versus 0 to 0.7 versus 0.3, and the temperature estimation errors were calculated.

RESULTS

Figure 1 shows the typical proton spectra(4). Nine fatty acid components were recognized in all the samples. The relationships between temperature and T1 of two major components, methylene chain (-CH2-) and the terminal methyl (CH3), are demonstrated with the spectra. The temperature relationships were linear with no hysteresis. The temperature coefficients for -CH2- and -CH3 were significantly different to each other; in this example, the coefficient for -CH2- was 11.5 ms/°C, while that for -CH3 was 37.1 ms/°C. Such temperature dependences and their differences were observed consistently in all the samples as are demonstrated in Fig. 2(a). Figure 2(b) and (c) show the T1 values and the relative value of the temperature coefficient at 30°C. Figure 3 shows the temperature error evaluated when the temperature calibration of T1 of pure -CH2- signal was used for estimating the temperature in a tissue with different mixing ratio of -CH2- and -CH3.

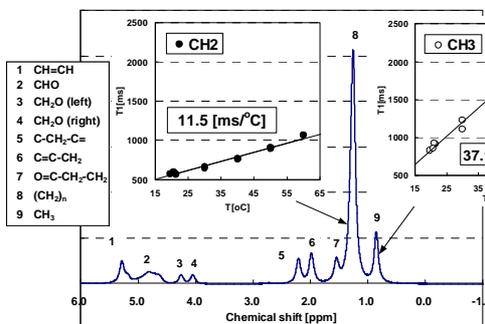


Fig. 1 Typical proton spectra shown with the relationships between T1 and temperature for -CH2- and -CH3 in a bovine fat sample in vitro at 11 T.

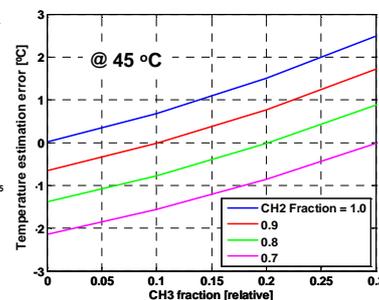


Fig. 3 Temperature estimation error in the case of using the temperature coefficient of T1 of pure -CH2- for the tissues with different mixture ratio of -CH2- and -CH3 heated from 30 °C to 45 °C.

DISCUSSIONS

The markedly longer T1 value of the olive oil in the deuterium solution shown in Fig. 2(b) was due to the low viscosity of the sample. The T1 values for the other samples were similar within the -CH2- and -CH3 groups. In all the samples, T1 and also T2 (results not shown) depended on temperature linearly in -CH2- and -CH3 in both vegetable oil and animal fat with correlation coefficient being 0.980-0.995. The temperature coefficients [ms/°C] of -CH2- and -CH3 in each specimen differed to each other by the factors of 2 to 3, while those were close among the samples (except for the oil solved in the deuterium solvent). In the 5 bovine samples the temperature coefficients of -CH2- were 11.6 ± 0.42 [ms/°C] demonstrating high reproducibility. Figure 3 shows that the inconsistency in -CH2- versus -CH3 ratio causes considerable deviation like 2.5 °C for 15 °C temperature elevation with 30 % of -CH3 signal contamination in temperature estimation due to the difference in the temperature dependences of the two components.

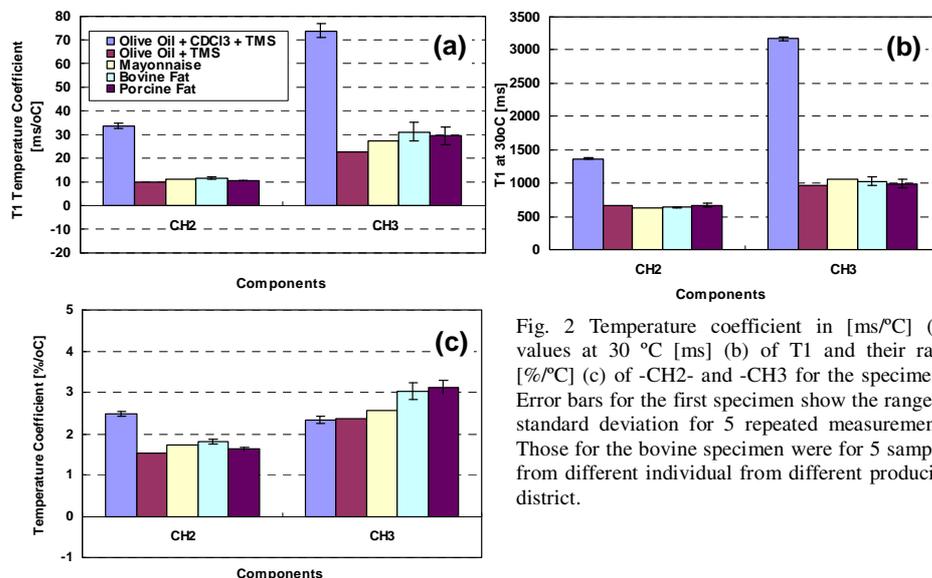


Fig. 2 Temperature coefficient in [ms/°C] (a), values at 30 °C [ms] (b) and their ratio [%/°C] (c) of -CH2- and -CH3 for the specimens. Error bars for the first specimen show the range of standard deviation for 5 repeated measurements. Those for the bovine specimen were for 5 samples from different individual from different producing district.

CONCLUSION

In quantitative fat temperature imaging based on the relaxation times, separation of the fatty acid components would be significant to improve the accuracy. Temperature coefficient compensation using MRS pre-calibration or direct and selective measurement of the particular fatty acid component, -CH2-, using multi-point DIXON technique(5) may be effective and is under our development.

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