Proton Density Ratio Consideration in Optimizing Image Processing in Fat-Water Thermometry using Methylene T1 and Water 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, bone marrow or other tissue locations with abundant fat contents. To meet such a clinical requirement, we have proposed a fat thermometry method(1) based on the temperature dependence of T_1 of methylene (CH_2) protons(2). The method was combined with the water proton resonance frequency (PRF) shift measurement to obtain integrated temperature maps for both fat and water(1). Since the method uses multiple flip angle(3), multipoint Dixon acquisitions and the least square estimation(4) techniques, a great deal of optimization for signal acquisition and processing is necessary. Echo time settings, signal modeling including the number of variables, frequency assignments and field offset are important for the proton component separation, whereas flip angle settings are important for T1 calculation. The difficult part of applying the water-fat separation technique to thermometry is the thermal shift of water resonance. The water signal will be on resonance only before treatment, because our particular method will use the relative water resonance shift for measuring temperature of high water content tissues, in which the fat internal reference is not available. In addition to the tips given by the pioneer works (4) for optimizing the water-fat separation in general, one of the key issues is to reduce the degree of freedom in solving the signal separation formula. In this attempt, we have examined how stable the density ratios among different fat proton components during temperature change.

METHODS

Measurements were conducted for bovine and porcine fat samples in vitro (N = 5 for each). The samples were from different individual animals of different producing areas in Japan. Each sample was put in a glass tube of 5mm in diameter. Small portions (~ 2-3 mm in size) of the specimen were stuffed into the sample tube tightly to avoid invasion of air bubbles. When bubbles were recognized with eye inspection, they were manually removed by using a syringe with a long tubing needle. The samples were then set in an 11T spectrometer (Bruker AV500, Xwin-nmr ver 3.0). Sample temperature was maintained at room temperature first, and then raised to be at 30, 40, 50 and 60 degree C, and then lowered at the same temperature steps by using an air blower device equipped with the spectrometer. At each temperature setting, T1's of different chemical shift components of the fatty acids were measured with a traditional IR sequence with two FID signal acquisitions at 8 different inversion times, 200, 400, 600, 800, 1000, 1200, 1400 and 16000 ms with TR of 20 sec. The data were then processed with a Marquardt-Levenberg non-linear least mean square software equipped with the spectrometer system. The signal with the longest TI value was used for measuring the proton density ratios.

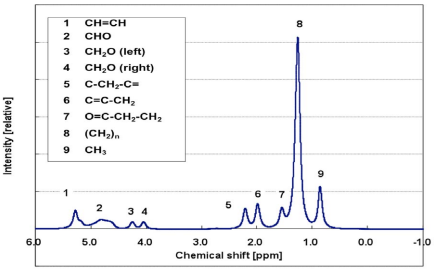

Fig. 1 Typical spectra from a bovine fat sample at 11T.

RESULTS

A typical proton spectrum of a bovine fat sample is shown in Fig. 1. Figure 2 shows temperature coefficients of T1 of all the fat proton components. The relative density fractions of CH_2, CH_3 and other proton components at different temperatures were obtained as Fig 3. Correlation coefficients between temperature and the signal fractions, and the significance levels of the coefficients are shown in Table 1. The correlation was significant only for a few low density components, 3 and 4. The other components maintained constant signal fractions in the temperature range used here.

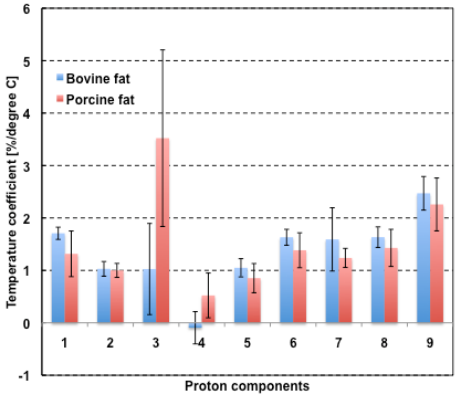

Fig. 2 Temperature coefficient of the proton compnents in bovine and porcine fat.

Table 1 Correlation coefficients between temperature and relative density ratios among the fat proton components in animal specimen. The values are the averages for five different samples. The significance levels

	1	2	3	4	5	6	7	8	9
	CH=CH	CHO	CH_2O	CH_2O	O=C-CH_2	C=C-CH_2	O=C-CH_2-CH2	CH_2	CH_3
Bovine	-0.659	-0.280	0.945	0.897	0.467	-0.034	-0.109	-0.177	0.463
	(p = 0.113)	(0.525)	(0.001)*	(0.003)*	(0.129)	(0.183)	(0.188)	(0.430)	(0.322)
Porcine	-0.782	-0.768	0.969	0.817	0.570	-0.440	0.104	0.548	0.124
	(0.014)	(0.053)	(0.006)*	(0.060)	(0.147)	(0.281)	(0.413)	(0.165)	(0.495)

*Significant

DISCUSSIONS

In this study, simple FID was observed to examine the change in the proton density fraction. The results in Fig. 2 are an extension of our previous observation to investigate the change in T1 not only in CH2 and CH3 but also in the other smaller peaks, which may affect on the fat signal separation. In contrast to the clear dependency of T1 on temperature, Table 1 suggests that most of the proton component have insignificant change with temperature. Although the proton density of bulk fat is known to be temperature dependent with irreversible manner, the present results suggest that the temperature change in the proton density ratios among the components may be negligible. Thus the ratios may be fixed in the signal separation model, so that the unknown parameter for fat signal can be the amplitude and frequency of either the total or methylene fat. The relative amplitudes and spectral positions of the other individual peak may be derived from the previously measured spectra of the target tissue region. This will greatly reduce the degree of freedom in the signal estimation resulting in stable temperature estimation using both methylene T1 and water PRF.

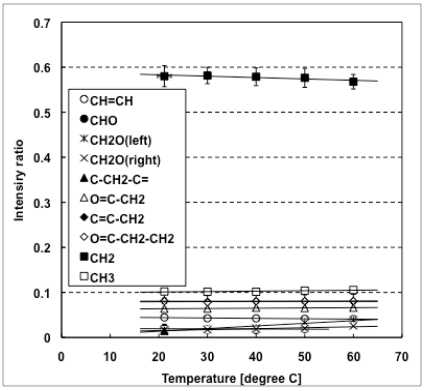

Fig. 3 Relative density ratio of the fat proton components at different temperature.

CONCLUSION

The present results can be a base for simplifying the mathematical model for the fat-water temperature imaging technique. Thermal shift of the water resonance can then be a variable to be estimated through linearization of the signal phase term. The effect of J-coupling in the fat proton components (5) should also be considered to know the exact density ratios in the target tissue using volume selective MRS techniques.

REFERENCES

1. Kuroda K, MK Lam, Iwabuchi T, Obara M, Honda M et al. Proc Intl Soc Mag Reson Med 2011;19:528.
2. Kuroda K, Iwabuchi T, Obara M, Honda M, Saito K, Imai Y. Magn Reson Med Sci. 2011;10(3):177-83.
3. Deoni SCL, Rutt BK, Peters TM. Magn Reson Med. 2003;49:515-26.
4. Reeder SB, Hargreaves BA, Yu H., Magn Reson Med. 2005;54:586-93.
5. Yahya A, BG. Fallone BG. J Magn Reson Imaging. 2010;31(6):1514-21.