

Effect of Water Resonance Thermal Shift on Methylene T1 Estimation with Multiple Flip Angle Multipoint Dixon Technique for Fat Temperature Imaging

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INTRODUCTION

High intensity focused ultrasound is an upcoming method for the treatment of breast cancer. To steer the focal point and to monitor thermal deposition around the focus, real-time temperature mapping is required. The conventional water proton resonance frequency shift method works only for high-water content tissues. For tissues with a large fat content like breast, a thermometry technique for fat is desired. This can be achieved by utilizing the temperature dependent T_1 -maps of the individual fatty acid proton components like methylene (CH_2) and methyl (CH_3) (1). In this new T_1 -based technique, multipoint Dixon acquisitions with multiple flip angles are used with a least square estimation scheme (2). Here, the resonance frequency changes of water proton with temperature affects the separation of the chemical species and thus the estimation of T_1 of those species. Therefore the frequency separation between the fatty acid species and water should be updated according to temperature elevations. In this study, numerical simulations were performed to investigate the effect of the water resonance shift to the T_1 estimation accuracy and to determine the real-time adjustment strategy to reduce the effect.

METHODS

A homogeneous numerical phantom with a $\text{H}_2\text{O} : \text{CH}_2 : \text{CH}_3$ density ratio of 5 : 4 : 1 was created using Matlab. The phantom signal S , assuming the use of the SPGR sequence, was the sum of the signals of each component as shown in the model function below;

$$S = \sum_{j=1}^3 \rho_j \frac{(1 - \exp(-TR/T_{1,j}(T))) \sin(\alpha)}{1 - \exp(-TR/T_{1,j}(T)) \cos(\alpha)} \exp(i2\pi\Delta f_j(T)t_n) \quad [1]$$

where ρ_j is the density of a j th component, $T_{1,j}$ is the T_1 value of the j th component, α is the flipangle, Δf_j is the frequency separation of the j th component and t_n is the n th echo time. The phantom with components H_2O ($j = 1$), CH_2 ($j = 2$) and CH_3 ($j = 3$) was designed to have $\Delta f_1 = 0$, $\Delta f_2 = 448$ and $\Delta f_3 = 480$ Hz relative to the on-resonance water signal and $T_{1,1} = 750$, $T_{1,2} = 300$ and $T_{1,3} = 700$ ms. These settings were based on a magnetic field strength of 3T and a normal body temperature of 37°C. The imaging parameters in this simulation were TE, 0.3667 ms, which is equal to Δt for $t_n = n \Delta t$; TR, 36 ms; number of echoes, 5. The components were separated based on the multiple echo data using the IDEAL algorithm proposed by Reeder (2). Such signal separation was performed for the data sets with the multiple flip angles (20°, 50°, 70°) required for the T_1 calculations based on Deoni (3). Comparison was performed between true of $T_{1,2}$ and $T_{1,2}$ based on the different settings of the frequency separations, where $T_{1,2}$ is the T_1 value for the CH_2 component. For the evaluation at multiple temperatures, the temperature coefficient of $T_{1,2}$ was assumed to be 2%/°C and the thermal shift of water proton resonance frequency was assumed to be -0.01 ppm/°C. Thus the error in the $T_{1,2}$ estimation was evaluated at different phantom temperatures.

RESULTS

The resulting ρ_j values from IDEAL showed a successful separation of the three components in the phantom. At equal temperatures of the phantom and the chemical shift setting, the calculations showed true T_1 values. Thus the T_1 mapping was successful. When the chemical shift setting is not right, T_1 estimation had error because of the incompleteness in the least square calculation. The comparisons between the true and calculated T_{1,CH_2} value changes are summarized in Figure 1. The error in $T_{1,2}$ values, shown in Figure 2, increases with increasing difference between the phantom temperature and the temperature setting of the chemical shifts. For a difference of -10°C and +10°C, the error in $T_{1,2}$ will result in a calculated temperature error of +4°C and -8°C respectively. For a more negative difference (< -10°), the $T_{1,2}$ error will increase drastically.

DISCUSSION

The error in $T_{1,2}$ values is different for the positive and negative differences between the phantom temperature and temperature setting of the chemical shifts. Also, the error increases drastically with a more negative difference (< -10°C). The sources of these behaviours might be in the incorrect calculations of the field map through the least square calculation process and should be further investigated. The simulation results suggest that adjustment of the frequency separation is needed for the $T_{1,2}$ -based temperature quantification.

CONCLUSIONS

The results show that the error in $T_{1,2}$ can be minimized by real-time adjustment of the chemical shifts with increasing temperature. To achieve a temperature accuracy of for example $\pm 4^\circ\text{C}$, the chemical shifts should be adjusted for at least every 5°C of temperature elevation.

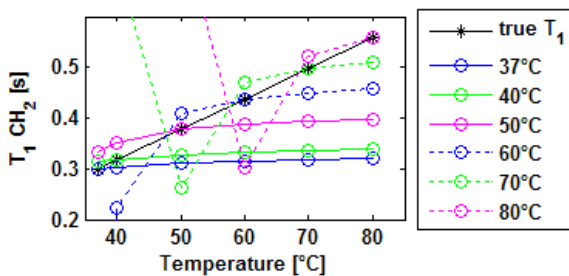


Figure 1 Comparison between true $T_{1,2}$ ($T_1 \text{ CH}_2$) (*) and $T_{1,2}$ estimated with fixed frequency separations for the chemical species (o) for different phantom temperatures (see legend).

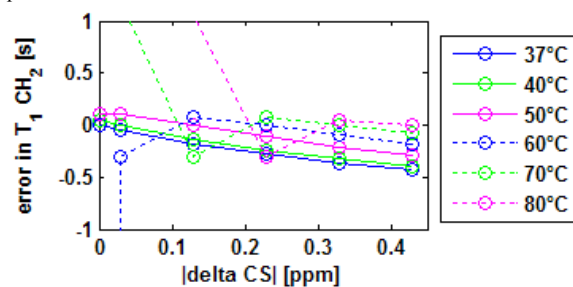


Figure 2 Relative errors in $T_{1,2}$ ($T_1 \text{ CH}_2$) changes with absolute chemical shift corrections relative to the chemical shift at 37°C ($|\Delta \text{CSI}|$), for different phantom temperatures. The graph is normalized to the true $T_{1,2}$ changes.

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