MR-Guided Thermal Ablation in Bone Using a Rapid Chemical Shift Imaging Technique

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Introduction

Thermal therapies are more frequently being used for treatment of primary or metastatic bone lesions (1). Typically, image-guidance techniques with MR or CT are used for treatment localization, planning and verification. However, the ability to achieve real-time quantitative monitoring of temperature changes during treatments in the bone is limited. For example, in MR the use of the complex phase difference (CPD) technique is hindered due to heavy intravoxel lipid contamination in the marrow in addition to susceptibility effects near bone and soft tissue interfaces (2). In this work, we investigate the use of a fast chemical shift imaging (CSI) technique for temperature monitoring in bone during therapy. This technique has the ability to provide spatiotemporal resolutions of CPD techniques while overcoming artifacts from intravoxel lipid contamination and can use the temperature-insensitive lipid as an internal reference for susceptibility and field drift corrections (3). We demonstrate this with real-time guidance of thermal therapies in canine femurs *ex vivo*.

Methods

Interstitial laser applicators (980-nm) were placed into the yellow marrow of freshly excised canine femur under MR-guidance. A fluoroptic probe was inserted 0.5 cm from the laser source in order to provide an absolute measurement of temperature. Image acquisition was performed using a multiple gradient-echo at 1.5T (ETL=16; minimum TE=2.1 ms; ESP=3.2 ms; TR=70; FA=30°; rBW=244 Hz/pixel, acquisition matrix=128x128; voxel volume=1.6x1.6x4.0 mm^3; 5 sec/image). The Steiglitz-McBride (SM) algorithm was used to calculate the PRF, T2*, and T1-W amplitude of water and/or lipid (bulk methylene) in each voxel (3). A nine-pixel ROI near the fluoroptic probe was created and the PRF of water and bulk methylene were measured as a function of temperature to calculate the temperature sensitivity coefficient (TSC). Additionally, noise estimates from each parameter (water and bulk methylene PRF, T2* and amplitude) were measured with the PRF uncertainties compared to temperature uncertainties from the complex-phase difference closest to the water T2*. Another bone was used to perform an external laser ablation. The multi-gradient echo was implemented at 3.0T (ETL=16; minimum TE=1.9 ms; ESP=1.8 ms; TR=68; FA=40°; rBW=325 Hz/pixel, acquisition matrix=128x128; voxel volume=1.6x1.6x5.0 mm^3; 5 sec/image) to demonstrate the use at higher fields even in the presence of gradient power constraints. Spectra from the acquisition were processed as a four-peak model comprising terminal and bulk methylene protons, methyl protons, and water protons. Temperature estimates were made by measuring changes in the water and bulk methylene PRF values. Additionally, estimates of the PRF, T2*, and amplitude of each peak were measured over 60 acquisitions.

Results

Correlations to temperature were found in multiple parameters provided by the high spatiotemporal resolution acquisition with the SM algorithm. Figure 1 shows the change in the water (squares) and bulk methylene (circles) PRF as a function of temperature at 1.5T. The temperature sensitivity coefficients (TSC) calculated from these plots are -1.08e-2 ± 1.0e-4 ppm/°C for the water PRF (R^2=0.981) and -0.20e-2 ± 1.0e-4 pppm/°C for the lipid PRF (R^2=0.438). Additionally, the TSC of the difference between the water and bulk methylene PRF values (-0.87e-2 ± 4.0e-6, R^2=0.961) were found to be consistent with measurements made in a homogenous fat-water phantom (2,3). A correlation with temperature was also seen with the water amplitude at -0.70%/°C (R^2=0.844). By taking the sum of the signal over 16 echoes, the TSC was found to be -0.56%/°C with a high correlation (R^2=0.927). Noise estimates for the water and bulk methylene PRF were 0.00372 ± 0.00052 and 0.00213 ± 0.00031 ppm, respectively. Using the calculated TSC values, this cumulates to a 0.70 ± 0.10 °C uncertainty when the difference of the water and bulk methylene PRF values was used for temperature measurements. Comparably, the uncertainty in the CPD was measured as 1.31 ± 0.17°C. The mean values (± one standard deviation) for the T2* for water and bulk methylene were 55.3 ± 2.8 and 26.8 ± 0.5 ms, respectively. The coefficient of variation of the amplitudes were 1.1 ± 0.1% for water and 1.7 ± 0.2% for bulk methylene protons. Figure 2 displays spectra from one 1.6x1.6x5.0 mm^3 voxel at 17.2 °C (blue) and 34.8°C (red) at 3.0T. Three lipid peaks were detected at 3.0T whereas only one was detected at 1.5T. At 3.0T, there was little temperature dependence between the terminal and bulk methylene protons' PRF with correlations of 0.345 and 0.435, respectively. The methyl protons have a relatively higher correlation to temperature at 0.713. Using the Steiglitz-McBride algorithm, peaks are plotted separately with precise PRF, T2*, and amplitude values for each peak as shown in Table 1.

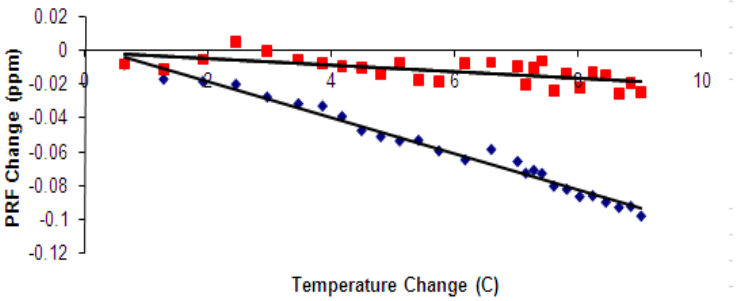

Figure 1: Temperature calibration performed via plotting the PRF of water (blue) and bulk methylene (red) versus measured temperature. The temperature sensitivity coefficient is the slope of the regression curve.

Peak	PRF (ppm)	T2* (ms)	Amplitude (A.U.)
Terminal Methylene	2.071 ± 0.015	7.10 ± 0.354	0.216 ± 0.009
Bulk Methylene	1.315 ± 0.007	20.1 ± 0.161	1.593 ± 0.002
Methyl	0.925 ± 0.004	18.5 ± 0.719	0.423 + 0.003
Water	4.701 ± 0.009	43.1 ± 0.895	1.000 ± 0.007

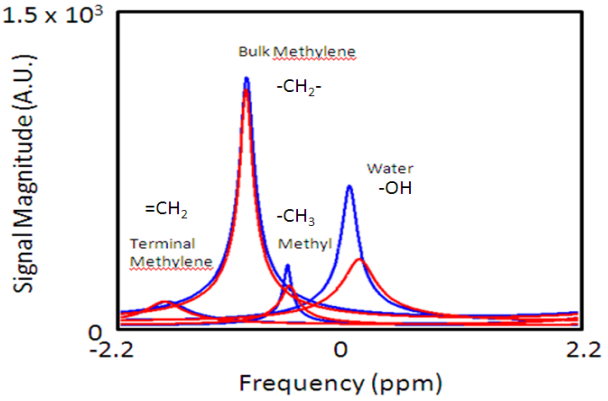

Figure 2: Measured spectra from one voxel in bone marrow at 17.2 °C (blue) and 34.8 °C (red) using the multi-gradient echo acquisition (ETL=16) at 3.0Twith the SM algorithm (3). Terminal and buk methylene, methyl, and water protons were detected and separated demonstrating multi-peak monitoring at high spatial and temporal resolutions (1.6x1.6x5.0 mm^3; 5 sec/image).

Conclusions

The published CSI technique (3) can provide measurements of temperature in bone marrow at high spatiotemporal resolutions where CPD techniques are currently limited due to intravoxel lipid contamination. The technique allows a rapid acquisition without time or SNR-consuming lipid suppression and preserves the lipid signal for internal correction. Temperature calibrations seen in this study are consistent with those seen in lipid-containing materials. The ability of monitoring more than one lipid peak at high spatiotemporal resolution is demonstrated and more studies are needed to compare each lipid peak's temperature sensitivity to determine its potential use for internal referencing.

References

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