Experimental Study of Model-Based PRFS Method on Motion and Field Drift Effects

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Introduction A novel MR temperature model based on proton resonance frequency shift (PRFS) and using fat as the internal reference has been proposed in our previous work (1) in which the reference image before heating becomes unnecessary. Therefore, theoretically the inter-scan motion or deformation and field drift induced quantification errors which are often encountered in conventional phase mapping PRF thermometry can be greatly reduced at the same time in the new method. To validate such improvement, specific-designed phantom experiments were conducted to demonstrate the feasibility of the model in handling motion and field drift related problems here, and the results were also compared to those of the phase mapping method.

Method Newly proposed model using fat as the internal reference can be fitted into the signal by the extended Prony algorithm to estimate the chemical shift between water and fat which contains absolute temperature information. In data acquisition, multi-echo GRE sequence with adequate echoes is used for the spectrum estimation. All phantom experiments were conduct on a 1.5T MR scanner (Sonata; Siemens Medical Solution, Erlangen, Germany) and imaged using a single element head receive-only coil. Whipping cream that has 36% of fat mixed with agar was first boiled and then cooled down to become solid jelly.

In the motion experiment, the phantom was fixed in a boiled water container to avoid the phantom movement in the flowing water. To simulate the motion, the phantom was repositioned along Superior/Inferior direction manually between every two scans. During the whole experiment with 25 consecutive scans, the largest displacement of the phantom was about 5cm. Every scan consisted of a single-echo GRE with fat suppression and a 12-echo GRE. The imaging parameters of multi-echo GRE were TE_0/ΔTE/TR/BW/Flip Angle/FOV/Slice Thickness/Data Matrix/Scan time =3.5ms /3.44ms/60ms/±38.4kHz/25°/30cm×30cm/5mm/128×128/8s. Fat suppression single-echo GRE with the same protocol as multi-echo GRE except TE=15ms was used for the phase mapping method as a comparison. The changes of temperature were measured by a thermocouple (Physitemp Instruments, Inc., New Jersey, USA). In the field drift experiment, the whipping cream phantom was first placed in the scan room before scanning until it reached the room temperature and became stable. During the whole imaging process, the temperature was constant. To simulate the effect of field drift, a piece of clip taped to a woody stick was placed inside the magnetic bore and repositioned between every two scans to create dynamic magnetic field disturbance. The same pulse sequences as in the motion experiment were used.

Temperature coefficient -0.01021ppm/^{o}C was used throughout the data analysis. To correct the susceptibility artifact caused by the thermocouple probe, the calculated chemical shifts in the non-affected surrounding region were extrapolated to replace those in the artifact-affected area using 2D data fitting with B-spline interpolation algorithm (2).

Results Fig.1(a) shows the phantom image with the calculated temperature change map at the 15th temperature point, the solid black box is the region of interesting (ROI) used for data fitting. Fig.1(b) shows the calculated temperature change map in the ROI before fitting, in which red arrow indicates the location of the thermocouple probe and dashed red circle covers the susceptibility-affected region, Fig.1(c) shows the calculated temperature change map in the ROI after fitting and the temperature change becomes smooth in the disturbed region. Fig.2 shows the temperature evolution curves measured by thermocouple and calculated from our method and the phase mapping method at the probe location during the phantom mimic motion experiment. The result indicates a very good agreement between our new method with chemical shift fitting and the thermocouple measurements. However, the result from the conventional phase mapping method shows the higher motion disturbance. Fig.3 shows the temperature evolution curves calculated from our new method and the phase mapping method during the mimic field drift experiment. The dynamic field change severely affects the temperature estimation of the phase mapping method with the maximum error about 60^{o}C (0.6ppm), while our method is insensitive to such fluctuant field with less than 1^{o}C error since the effect is canceled out by the subtraction of two species frequencies.

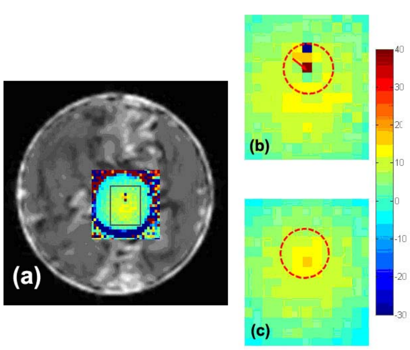

Fig.1: Phantom image and the calculated temperature change map at the 15th temperature point.

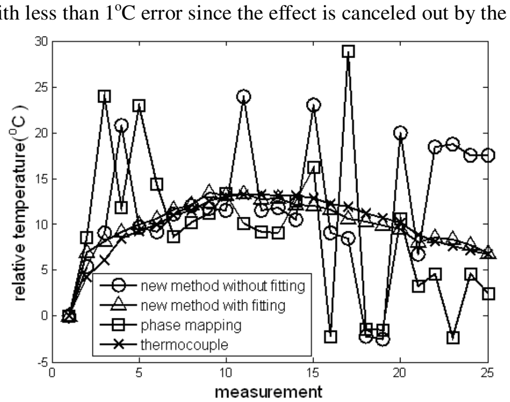

Fig.2: Temperature evolution curves during the mimic motion experiment.

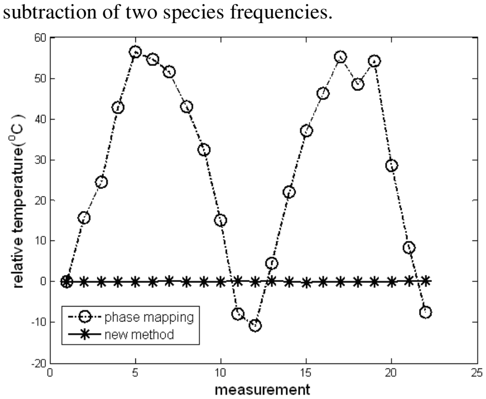

Fig.3: Temperature evolution curves during the mimic field drift experiment.

Conclusion Results of mimic phantom motion and field disturbance experiments demonstrate that new approach is much less sensitive to the disturbances caused by inter-scan motion and field drift. It is also demonstrated that the thermocouple probe induced susceptibility artifact in the temperature maps can be eliminated by the B-spline fitting of chemical shift.

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References 1. Pan X. et al., Proc. ISMRM, 2008 (1235). 2. Sandwell et al, Geophysical Research Letters 1987; 14:139-42.