Sensitivity Study of MR–Based Temperature Mapping at 7T

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INTRODUCTION

Noninvasive measurement and mapping of the spatio-temporal distribution of tissue temperature is important for the development and application of novel thermotherapy techniques in clinical oncology. MRI-based thermometry using the temperature sensitivity of proton resonance frequency (PRF) is a well-established method, and has been shown to provide useful information for thermal therapies in a variety of tissue organ sites in vivo [1, 2]. Typically, at low-field clinical scanners, the PRF shifts associated with the local tissue temperature changes are very small, and therefore, the sensitivity of temperature changes generated by the phase shifts is low. In this study, the sensitivity of MR thermometry at 7T was evaluated using an easy-characterized and controlled gel phantom, the temperature coefficient was computed based on linear fitting of the actual temperature vs phase difference. The absolute temperature maps were then calculated. The results indicated that a local temperature change of 1°C can be measured accurately.

MATERIALS AND METHODS

The cross-sectional image of the phantom used in this study is shown in Figure 1. The outer tube (2.7cm ID) was filled with regular agarose gel (1%). A soft tube (0.5cm ID) was inserted through the larger tube's isocenter where hot water can be injected to change the phantom temperature. A temperature probe attached to the small tube was used for real time temperature recording during the experiments.

MR measurements were performed using a 7T scanner (Bruker, Ettlingen, Germany), with a gradient coil capable of generating maximum gradient amplitude of 400mT/m. FLASH sequence was used to acquire the MR thermometry data, with TR=100ms, TE=2.6ms, and Flip Angle = 30°. Image matrix size of 128×128 with FOV of 3.5×3.5cm^2 were obtained at slice thickness of 2mm, with 4 averages for each slice. In the data shown below, 20 consecutive data sets were acquired, with the first 6 data sets as baseline references. The images were continuously acquired followed by the injection of hot water through the inner tube of the phantom. The local temperatures in the phantom were simultaneously monitored and recorded via the temperature probe connected.

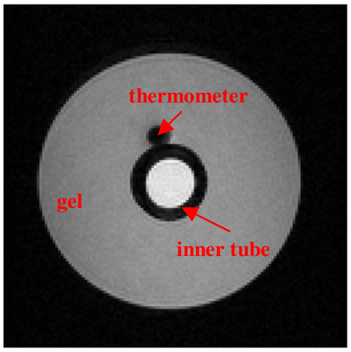

Fig.1.MR image showing the phantom details.

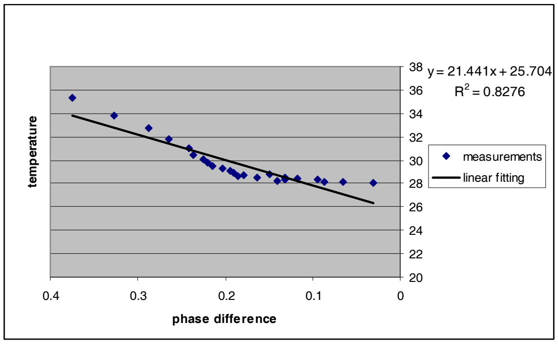

Fig.2. Linear correlation between temperature and phase difference.

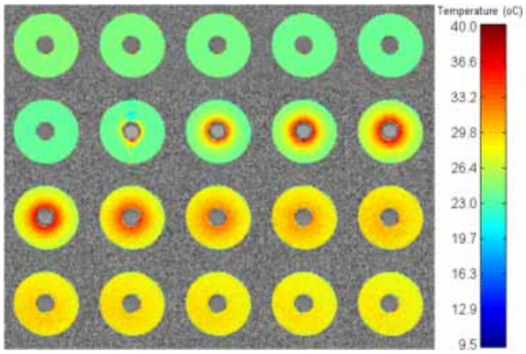

Fig.3. Temperature map.

The computation of the temperature maps were based on the phase difference image using equation, $\Delta T = \dfrac{\Delta\phi(x,y)}{2\pi\cdot\alpha\cdot f_0\cdot TE}$, where ΔT is the change of temperature (°C), $\phi(x,y)$ is phase difference (°), α is the temperature coefficient (ppm·°C^{-1}), f_0 represents the resonance frequency (MHz), and TE is echo time (s). The phase images acquired as the baseline were normalized, and the phase difference was computed in reference to the baseline data.

RESULTS AND DISCUSSIONS

Figure 2 shows the correlation between the measured temperature and the phase changes, from a selected range of temperature. A linear fitting was used in order to derive the temperature coefficient. From this experiment, the temperature coefficient was found to be $\alpha = 0.0095$ ppm·°C^{-1}, which is in agreement with previous report [3]. The data shown in Figure 2 was derived from a region of interest (ROI) that is close to the temperature probe so that the accurate correlation can be made. Combined with the actual baseline temperature, the absolute temperature maps are derived and shown in Figure 3. These results indicated that high accurate temperature mapping is feasible at 7T. The images also show that, after the injection of hot water, the heat exchange process can be visualized with high temporal and spatial resolution until it is finally equalized within the gel phantom.

CONCLUSIONS

In this study, the sensitivity of an MRI-based temperature mapping method was studied at 7T using PRF-based technique. The temperature coefficient calculated to be 0.0095 ppm·°C^{-1}. The average temperature difference that can be detected by this method is 1.01°C, indicating the current method for temperature mapping at the 7T is very sensitive. Future study will include evaluating this technique in vivo as applied to the development and application of novel thermotherapy techniques in the treatment of animal tumor models.

REFERENCES

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