MR Thermal Imaging at 3T – Potential SAR Monitoring Tool?

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Abstract

We demonstrate the feasibility and advantage of using the water proton resonance frequency (PRF) shift based MR thermal imaging technique to measure temperature change in a 3T scanner. The accuracy is adequate to monitor SAR related heating and can provide a more quantitative measure of specific absorption ratio (SAR) and potentially leads to better thermal models and overcome the SAR limitations that have hampered some of the 3T imaging protocols.

Introduction

MR imaging with 3T and higher field strengths have gained increasingly wider clinical acceptance in the last several years. However, due to the fact that RF related heating, which is characterized by the specific absorption rate (SAR), depends on the square of the field strength, many applications have been limited. The traditional model to calculate the SAR deposition has been based on numerically modeling [1] and limited *in vivo* study, and may prove to be overly conservative or inadequate. On the other hand, MR thermal imaging based on the Proton Resonance Frequency (PRF) shift has been developed for the non- or minimally invasive interventional procedures [2,3], mostly for medium and low field strength (1.5T or lower). The PRF shift based technique has not been demonstrated at high field strength. We hypothesize that by applying the PRF shift thermal imaging on 3T, we can take advantage of the higher signal to noise ratio (SNR) afforded by the increased field strength as well as the higher thermal sensitivity due to the higher resonance frequency.

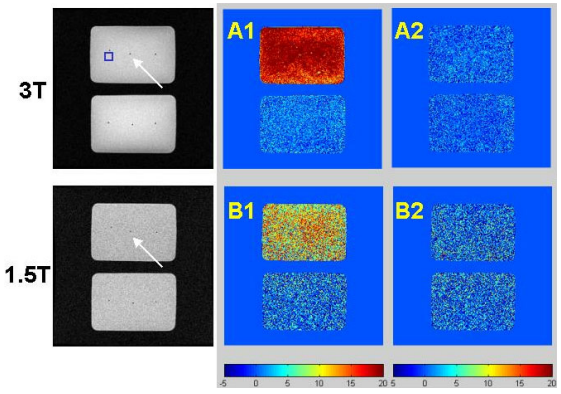

Figure 1 Phantom placement and thermal sensitive phase images. The numbers on the color scale indicates the phase change in degrees.

Methods

Two identical gelatin phantoms were placed in the center of a GE Signa 3T scanner (GE Medical Systems, Milwaukee, WI). Some T1 shortening Gd-DTPA contrast agent was added in the phantom to increase the SNR and in turn to improve temperature sensitivity of the measurement [4]. One phantom was kept at room temperature to monitor non-thermal related system phase drift (lower phantom in Fig 1). The other phantom was heated to 45°C and was cooled down during the course of 40 min (upper phantom in Fig 1). Three fiber optic thermal sensors (FISO FOT-L, Quebec, Canada) were embedded in each phantom to monitor the temperature change (see white arrows in Fig. 1). The temperature reading was recorded at 2 sec interval and was synchronized to the MR image acquisition. After the mask image was acquired, the thermal images were acquired every 30 sec with the following protocol: TR=7ms, TE=3.22ms, Flip Angle=30°, Bandwidth=±31.25kHz, slice thickness=5.0mm, acquisition matrix 256 × 256, FOV=32cm, scan time 1.87s. For comparison, the same experiment was repeated in a GE Signa 1.5T scanner under similar conditions. The protocol was kept identical to that of the 3T case with the exception of TE=3.30ms.

Region of Interest (ROI) analysis was performed on the thermal phase images. A square region of 10 pixels in each dimension was selected at a location close to the thermal sensor (shown in Fig 1) and the average phases in that region was calculated. This value was corrected for the system background phase drift to yield a phase change that is only sensitive to the temperature change. A linear fit was applied to the phase change and thermal sensor data to obtain the phase-temperature sensitivity and the correlation coefficient.

Results and Discussion

Figure 1 shows the magnitude images and the phase difference images both at the beginning (A1/B1) and at the end (A2/B2) of the cooling process. The SNR of the magnitude images are shown in column 1 in Table 1 and reflects a factor of 2 increases under 3T. This increased magnitude SNR results in better phase SNR in the phase difference image, which is characterize inversely by the standard deviation in the phase images (column 2 in Table 1). The correlation between thermally induced phase change and the temperature measurements are higher at 3T compared to 1.5T as shown in Fig 2. The correlation *R* is shown in column 3 in Table 1. The phase-temperature sensitivity is more than doubled at 3T compared to 1.5T. During the 40-minute scan, less than 1° system background phase drift was observed in the 3T system while the similar drift was under 1.5° in the 1.5T system.

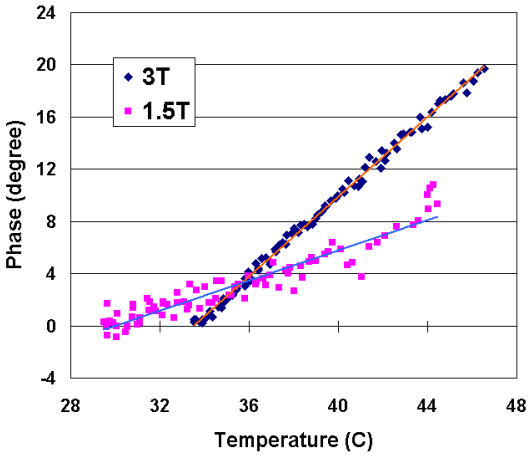

Figure 2 Phase-Temperature correlation of both the 3T and 1.5T cases.

	Magnitude SNR	Phase STD (deg)	Correlation R	Thermal Sensitivity (deg/°C)
3T	21.0	2.66	0.9978	1.529 ± 0.010
1.5T	10.0	5.96	0.9464	0.580 ± 0.022

Table 1 Results of SNR, phase standard deviation, and phase-temperature sensitivity.

Conclusion

We have demonstrated that the PRF shift based thermal imaging technique has increased sensitivity under 3T and can potentially be used in monitoring the RF heat deposition during a scan. This could provide a new measurement tool to help build more realistic thermal models for prediction of SAR deposition, even on a patient-by-patient basis. It could be used during the imaging sequence to interactively monitor and control the scan. It could also be used as a pre-scan calibration to determine the optimal scan parameters without violating the safety limit. This will allow further optimization of clinical protocols under 3T and potentially take advantage of the higher field strength. More investigation with non-homogeneous phantom and *in vivo* experiments are needed. The result also indicates that the interventional procedures can benefit from the higher strength as long as the instrumentation is made compatible to the higher field strength environment.

References

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