Simultaneous Monitoring of Temperature and Magnetization Transfer for HIFU Treatment

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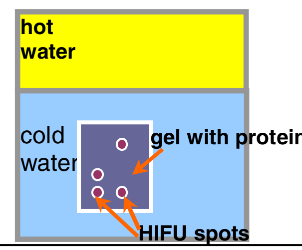
Introduction

Recently the development of high intensity focused ultrasound (HIFU) technology has offered a potentially new approach to the local ablation of cancer [1] or myoma. The utilization of MRI for guiding HIFU beams can not only greatly increase the localized accuracy during HIFU heating procedures but also can be used to evaluate the HIFU-induced lesions after treatments [2]. During the past few years, the temperature measurement procedure using phase mapping was developed that makes use of the temperature dependence of the water proton chemical shift [3] which is so-called proton resonance frequency (PRF) shift method. In addition, the changes in magnetization transfer (MT) contrast of tissues after heat treatment was also evaluated in a previous study [4]. A real time evaluating method, that includes temperature monitoring as well as MT contrast of thermal damage during sonication, should be helpful to improve the heating efficiency of HIFU beams and to avoid the damage of adjacent normal tissues. Our study investigated the feasibility of estimating temperature change and MT contrast simultaneously during HIFU heating treatments.

Materials and Methods

A special phantom setting (Fig.1) was designed to verify the feasibility of observing temperature change and MT contrast simultaneously. The upper hot water was set up for monitoring temperature change during scanning, while the lower part contained a gel phantom immersed in cold water, with the gel having spots pre-treated with HIFU heating to observe the change of MT ratio (MTR). The HIFU power and heating time of each spot was listed in Table 1. Two sets of MT phantom were used, one using fixed HIFU power (60W) with varying heating time, and the other with varying HIFU power at constant heating time (30s). All MR images were acquired on a 3T clinical imager (Siemens Trio, Erlangen, Germany). The pulse sequence used a dual gradient-echo design, with ON and OFF of the MT pulse interleaved (Fig.2), such that the phase images from the two gradient echoes could be used to estimate PRF shift in response to temperature change, and the first echoes from two consecutive TR could be used to derive MTR on a pixel-by-pixel basis [4]. Imaging parameters were TR=42, TE=4.52/20, flip angle=15^0, FOV=160x160 mm^2, matrix size=128x128, slice thickness=1.5 mm, off-resonance frequency of MT pulse=+500 Hz. For comparison, the temperature in hot water was continuously measured by a thermal meter (54II thermometer, FLUKE) placed near the bottom. To evaluate the MT contrast of spots with different HIFU heating conditions, we selected several ROIs from MTR images, as shown in Fig.3, and compare the difference of MTR values between HIFU-heated spots and an area without HIFU heating (“nor” in Fig.3).

Fig. 1.



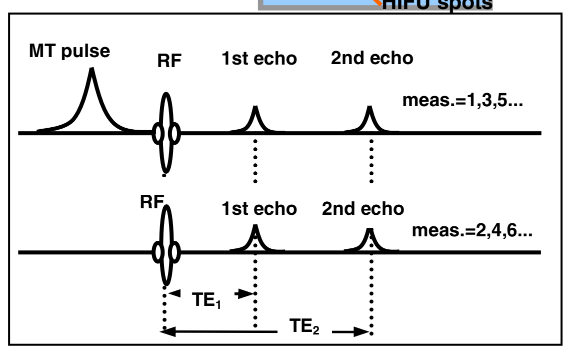


Fig. 2. The dual gradient-echo sequence interleaved with measurement with and without MT pulse, respectively.

Results

The temperature changes measured by MR PRF shift method in the bottom of hot water (ROI shown in Fig.3a) and by thermal meter were shown in Fig.4. The highly consistent estimation values indicated that MR PRF is a precise method for continuous temperature monitoring. The MTR contrast of HIFU-heated spots are shown in Table 1. The MTR contrast increased from 0.0397 to 0.0809 with increasing HIFU heating time, and increased from 0.0318 to 0.0874 increasing transmitting power from 70W to 90W. Both of the monotonic relationships are in agreement with the expectation of protein denaturation via HIFU heating.

Discussion and Conclusions

Monitoring temperature changes and protein denaturation during transmitting HIFU pulses is important for evaluating treatment efficiency. In our study, we verified the feasibility of simultaneous temperature monitoring and MTR measurement by MR imaging. The linearity of temperature changes measured by the PRF-shift method as validated using a thermal meter demonstrated the precision of the MR approach. Furthermore, the distinct changes of MTR contrast illustrated its potential usefulness to evaluate the degree of protein denaturation during HIFU transmission. We therefore conclude that MRI with simultaneous temperature estimations and MT measurements is an effective technique that could help monitoring HIFU treatment by reflecting local heating conditions and progress of protein denaturation. The proposed method should be beneficial to the improvements of HIFU heating efficiency and could decrease unnecessary heating damage to tissues nearby the targeting area.

Table 1

Phantom 1			Phantom 2		
power (W)	time (sec)	MTR contrast (a.u.)	power (W)	time (sec)	MTR contrast (a.u.)
60	60	0.0397	70	30	0.0318
60	70	0.0710	80	30	0.0573
60	80	0.0809	90	30	0.0874

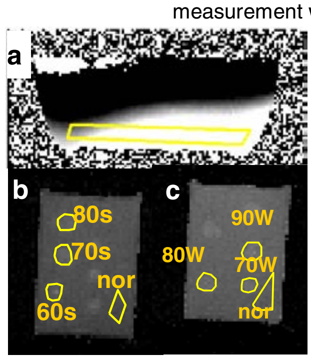


Fig. 3. (a) Phase image of hot water; (b) MTR image of Phantom 1. (c) MTR image of Phantom 2. The yellow lines were the selected ROIs. “nor” stand for area without HIFU heating.

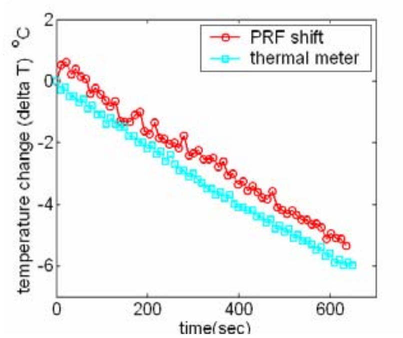


Fig. 4. The temperature changes which were measured by MR PRF shift and thermal meter during MR scanning. High correspondence of these two methods are noticed.

References

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