

Monitoring of HIFU Treatment Effectiveness by MR Imaging: An Ex-Vivo Studies with Multi-Spot Heating

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Introduction

High intensity focused ultrasound (HIFU) provided tissue destruction or tumor ablation in a non-invasive way, which was one of the promising thermotherapy techniques [1]. Combined with the MRI techniques, MR-guided focused ultrasound (MRIGFUS) generally utilized the PRF-shift thermometry to monitor the temperature in the targeted tissue in real time [2]. To further improve the monitoring of the treatment process, our group has shown that magnetization-transfer-prepared (MT) gradient-echo sequence is a practical tool to simultaneously monitor the temperature change and MT contrast during HIFU energy transmission [3]. In the present study, we improved the previous experiment with a movable HIFU transducer mimicking the real treatment process and presented a new analysis approach similar to the correlation method detecting the “activation” regions in functional MRI studies. The efficiency of the MT/temperature measurement method and the statistic mapping was demonstrated by multi-spot heating experiment in consecutive time.

Material and Methods

The HIFU device consisted of a home-made tank (54×35×23 cm³) filled with 37°C degassed water and a HIFU transducer (central frequency 1.85 MHz, 10 cm diameter, 12.5 cm curvature, Imasonic, Besancon, France). The two-axis motion (X-axis and Z-axis of the scanner) of the transducer fixed on the slide shafts can be manually controlled. An acoustically transparent membrane and gel were fixed by an acrylics plate and placed on the top of the water tank to couple the HIFU energy to the targeted porcine muscle (15~20 hr after death). All MR images were acquired in 3T MR system (Siemens Trio, Germany). The MTR images of porcine muscle were acquired by the dual-echo gradient-echo sequence with alternated MT pulses (TR/TE:29/3.57,7.53 ms, FOV:300×225 mm², flip angle:20°, matrix size:128×128, slice thickness:3 mm, transmitter coil: body coil, receiver coil: abdomen phase-array, measurement number:192, the temporal resolution ~2.8 sec, MT off-resonance frequency: -1200 Hz). The acquired images were processed by using Matlab® (Mathworks, USA).

To study the MT/temperature changes during a multi-spot HIFU treatment, we designed a time series of turning on and off HIFU pulses alternately, which performed on four different positions (the distance between each other was 15 mm), as shown in Fig. 1a. Three trials (HIFU power: 30~40 Watt) were done on different porcine muscles. For the data analysis, the long-echo phase images with long echo time were used to calculate the PRF shift and to derive the temperature change, meanwhile, the short-echo magnitude images were used to generate MTR images [3]. Moreover, a pixel-by-pixel correlation analysis was applied on the MTR images. The paradigm for correlation was a sliding-window step function. A CC_{Max} map was generated by finding the maximum correlation-coefficient of all the windows to observe the statistical significance of MTR change in each pixel.

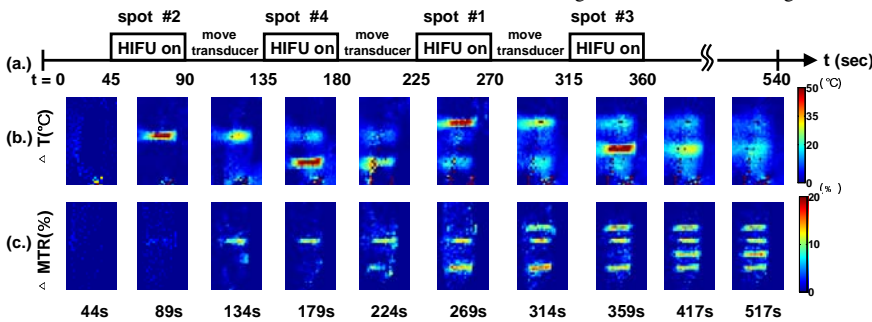


Fig.1 (a): Designed time series of switching HIFU power (b): the calculated temperature change maps (c): the estimated MTR change maps, all the maps were rendered in pseudo-color maps.

Results

Fig. 1b and Fig. 1c respectively show the temperature and MTR change at three different stages (pre-heating, heating and post-heating). We can notice that the temperature rose after heating and fell gradually after turning off HIFU power, whereas the MT effect retained after heating. The corresponding optical image of the heated area is shown in Fig. 2(a). The calculated CC_{Max} map is overlaid on the original gradient echo image. The threshold of correlation coefficient (CC) is 0.5 and the pixels with less than 2 contiguous pixels with high enough CC are excluded (see Fig. 2(b)). Notice that the localization and the shape of the four coagulated tissue spots are very similar in three type of images (delta MTR, optical image, and CC_{Max} map). Fig. 3 show the time-curve of delta MTR series. The MTR of four spots increased about 10~15% after HIFU heating and the alteration lasted to the end of the experiment.

Discussion and Conclusions

In our study, the MTR mapping, which was compatible to the widely used PRF-thermometry, was proposed to detect the tissue damage. In our experiment, we mimicked the procedure of the MRIGFUS thermotherapy by multi-spot heating and the heated area was imaged by the PRF/MT sequence. The resulted MTR image series showed that the tissue damages caused permanent MTR alterations and thus MTR-time curve can be considered as a step function. Using this property, a fMRI-like correlation analysis was applied on the MTR-time series to calculate the significance of MTR changes. The fMRI-like map which fused the CC and the anatomical magnitude images may help the recognition of the treated area and its spatial relation to the lesion area. To achieve the proposed method, an additional off-resonance irradiation is required and thus further investigations is required to address the potential influence of the field inhomogeneous. In conclusion, this method that can monitor temperature changes as well as the level of MT change opens a potentially useful window to observe the tissue coagulation due to the HIFU power transmission in real-time.

References

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- [2] Bruno Quesson et al, JMRI (2000) 12:525-533
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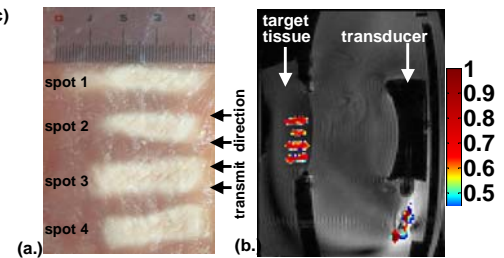


Fig. 2. (a) Optical picture of the porcine muscle after heating. (b)The CC_{Max} map overlaid onto on original magnitude image

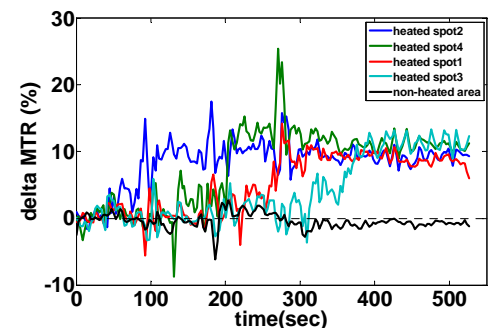


Fig. 3. The delta MTR changes of a multi-spot heating experiment. (HIFU power: 40 watt)