Temperature Error Reduction during MRI guided HIFU Treatment

X. ZHOU[1,2], Q. HE[1,2], Q. ZHANG[2], and C. NI[1,2]

[1]College of life science and technology, Tongji University, Shang hai, Shang hai, China, People's Republic of, [2]Siemens Mindit Magnetic Resonance Ltd., Shenzhen, Guangdong, China, People's Republic of

Introduction:

MR thermometry, based on PRF (Proton Resonance Frequency) shift, can provide optimized temperature accuracy and time resolution in tumor treatment by MRI guided High Intensity Focused Ultrasound (MRgHIFU). However, the challenge is that when ultrasound applicator moves, if reference image is not updated accordingly, temperature error will be observed due to applicator's magnetic susceptibility. During MRgHIFU treatment, the ultrasound applicator has to be moved to cover the whole tumor volume. Therefore reference image has to be repetitively acquired for new applicator position in conventional PRF-shift based temperature mapping method. Cooling down time has to be considered in order to get next reference image. The treatment workflow becomes complex and time consuming, which hinders a wider and effective application of MRgHIFU in tumor treatment. In this abstract, we propose a method to compensate ultrasound applicator susceptibility by calculated or pre-measured delta magnetic field distribution induced by ultrasound applicator. Treatment workflow is simplified and the total treatment time is much reduced.

Methods:

A simplified workflow of MRgHIFU treatment is shown schematically in Fig 1. After treating at position 1, ultrasound applicator moves to position 2 for the next ablation. MR temperature maps are acquired during treatment for monitoring treatment effectiveness. In a homogeneous magnetic field where there is no ferro-magnetic objects, as in the case of MRI where the ppm level variation of the B_0 field can be safely ignored, the spatial distribution of the applicator induced magnetic field is constant with respect to a coordination system fixed to the applicator when applicator only moves translationally or rotates along B_0 direction. Therefore if the spatial distribution of induced applicator field is known for one applicator position, for any other applicator positions, the induced field can be obtained just by translating or rotating the known induced field. The applicator induced magnetic field can be used to calculate delta phase when applicator moves during treatment. The temperature error due to applicator's susceptibility can be removed by subtracting the delta phase from conventional PRF-shift phase difference map. The applicator induced delta magnetic field for one position can either be calculated or pre-measured. 1) Calculation method: the ultrasound applicator volume is divided into small volume elements; the total induced delta field is the sum of field contributed by each volume element. 2) Measurement method: a non-magnetic water tank is set up in MR magnet bore; gradient echo phase images are acquired with and without applicator in the water tank respectively. Water level should be kept the same for both measurements. The applicator induced delta magnetic field can be obtained by subtracting these two phase images. A fixed focus ultrasound applicator is used in the experiment with 18cm in diameter and 15cm in focal length. Ex-vivo experiment with pork meat and phantom experiment were set up. All experiments were done on a 1.5T MR system (Avanto, Siemens) .

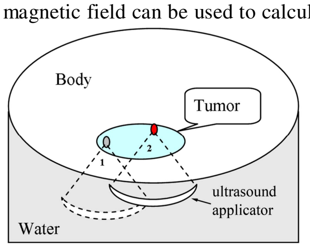

Fig 1, Reference image is acquired before treatment. The applicator need to be moved to cover the whole tumor volume. The same reference image is used for all applicator positions by our proposed method.

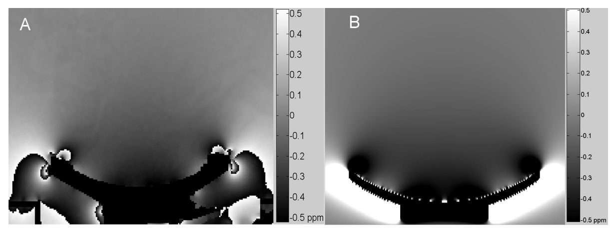

Fig 2, ultrasound applicator induced delta magnetic field. A) by measurement, B) by calculation. Phase wrapping can be observed around the applicator due to large magnetic field variation (A).

Results and Discussion:

Applicator's delta magnetic field was measured in the MR magnetic bore with a water tank as shown in Fig. 2A. Phase wrapping can be observed around the applicator where there is large magnetic field variation. The phase wrapping area does not affect the temperature monitoring since it is far away from the ultrasound focus region of interest. The delta field was also calculated as shown in Fig. 2B that demonstrates consistent result with the measured data in the ultrasound focus region. The benefit of the calculation is that highly accurate delta field can be obtained if the mechanical structure and magnetic susceptibility of the applicator material are known. Fig. 3A shows the temperature error caused by the applicator induced delta field in the conventional PRF-shift phase difference map when applicator shifts 3cm. In the ultrasound focus area of 10cm×10cm, an large error over 10°C can be observed. By re-acquiring reference image, the temperature error could be removed but re-acquiring of new reference should wait until tissue fully cools down, which typically takes 1~5 minutes. By compensating the induced delta field using our proposed method, the temperature error in the area is significantly reduced to less than 2°C as shown in Fig 3B. Fig. 4 shows the result of an ex-vivo experiment where the ultrasound applicator transmitted 200W for 4 seconds. If the applicator remains at the same position where reference image was acquired, there is no effect from the applicator susceptibility, and the temperature of the focus region is clearly shown in temperature map Fig 4A. As can be seen from Fig. 4B, large temperature errors can be observed in the lower corner when applicator shifts 8cm without compensating applicator's susceptibility and temperature map in the focus region is greatly affected. By employing the compensation method proposed by the authors, temperature errors are much removed and the ultrasound focus can be shown clearly in Fig 4C.

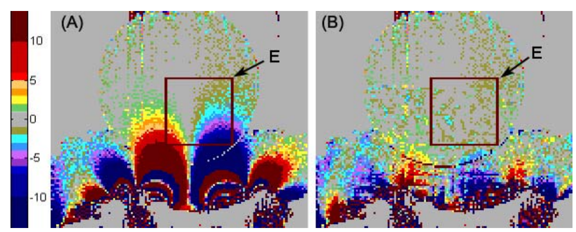

Fig 3, Temperature error maps due to applicator's magnetic susceptibility imaged with a 24cm sphere phantom. There is no ultrasound energy transmission and the applicator moved 3cm from the reference position. A) Temperature map without applicator susceptibility compensation, Over 10℃ temperature errors can be found in evaluation area E of 10cmx10cm . B) With applicator susceptibility compensation, temperature error can be removed.

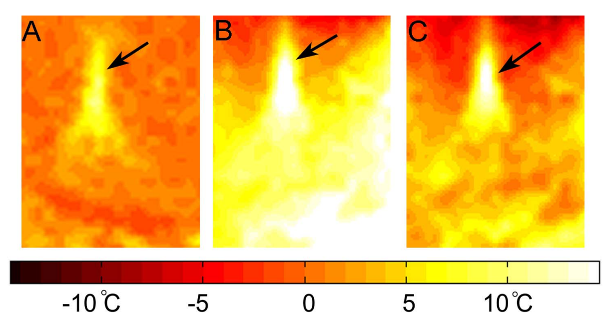

Fig 4, Temperature map of ex-vivo pork meat *using the same reference phase image for different applicator positions. Ultrasound focus is indicated by the arrow. A) Temperature map when the applicator remained at the same position as the reference image was acquired. B) Temperature map without applicator susceptibility*

Conclusion:

With the proposed method, long waiting time due to tissue cooling down and the intensively repetitive re-acquiring of reference images are avoided. Clinical workflow of MRgHIFU treatment can therefore be much improved regarding the complexity of treatment and the total treatment time.

Reference:

Q., Bruno, etc., JMRI 12:525-533 (2000)