Real Time MR Thermometry for Monitoring Focused Ultrasound in the Liver

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Introduction

Focused ultrasound (FUS) is a promising technique for the noninvasive treatment of liver tumors. The current challenges are twofold 1) obtaining good temperature information during motion and 2) slewing the beam in real time to a constant position in the liver. This abstract addresses the first of these challenges. In PRF thermometry, insufficient frame rate results in blurring and distorting of the hot spot. Lowering the resolution is not adequate, given the high temperature variation throughout a sonication spot. Thus, neither resolution nor speed should be sacrificed. The purpose of this work was to develop an MR thermometry pulse sequence that would provide accurate temperature imaging for monitoring focused ultrasound of the liver. We demonstrate the ability to accurately monitor temperature in a moving gel phantom, as well as demonstrate the image quality in vivo.

Methods

The pulse sequence consisted of three main elements: 1) outer volume suppression with polynomial phased RF pulses [1] surrounding the imaging region in the phase encode direction, 2) spatial-spectral excitation consisting of 3 binomial subpulses exciting only water, and 3) a multi-shot echo planar readout. For the initial phantom test, the specific pulse sequence parameters were TE = 14.1ms, TR = 40ms, 6.3x12.6cm^2 FOV, 1x1x4.7mm^3 voxel size, 7 flyback EPI interleaves, 3.62 fps. For the second phantom experiment and in vivo testing, the pulse sequence parameters were TE = 13.5ms, TR = 125ms, 8x8cm^2 FOV, 1.33x1.33x4.7mm^3 voxel size, 3 off-center flyback RS-EPI interleaves, 2.68 fps. All experiments were performed in a GE Signa Excite 3.0T scanner (GE Healthcare, Waukesha, WI).

The temperature processing was referenceless processing [2]. A region of interest, excluding the actual area of heating, was selected for each frame. The unwrapped phase of this ROI was fitted to a high order polynomial, and this was subtracted from the ROI, inclusive of the sonication region to create a temperature map. The pulse sequence and referenceless reconstruction algorithms were implemented in the RT-HAWK (HeartVista Inc., Los Altos, CA) real-time environment [3].

The phantom tests consisted of a polyacrylamide gel phantom, surrounded by a surface coil. It was heated with a 1000 element extracorporeal planar transducer (Insightec Ltd, Tirat Carmel, Israel) for 50 seconds. The first sonication occurred with the phantom stationary. The experiment was then repeated, moving the phantom and transducer in unison back and forth in the scanner to simulate respiratory motion. In the first experiment, which had a sonication power of 40W, all processing was perfomed in MATLAB (The Mathworks, Natick, MA) to analyze the maximum temperature measured in each sonication. In the second experiment, heating at 80W, ROIs were automatically centered on the sonication in RT-Hawk to test the combination of the pulse sequence and referenceless thermometry in real-time. The in vivo test consisted of a healthy normal volunteer imaged at 2.68 fps with an 8-channel coil. Images of the liver were acquired to assess the sequence temperature variation in physiological conditions.

Figure 1: *The maximum temperature in the moving case (blue) shows good agreement to that measured when the phantom was stationary (green) (top). The*

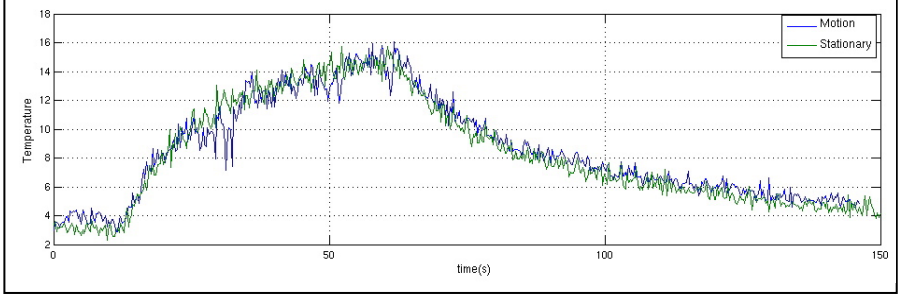
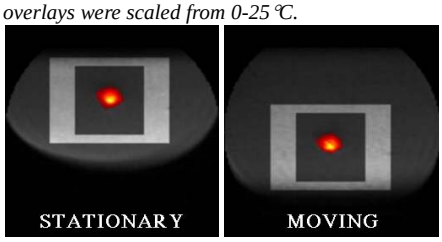


Figure 2: *Comparison of a stationary sonication (a) with a moving sonication (b). Temperature overlays were scaled from 0-25 ℃.*



Results

Figure 2 shows a plot of the maximum calculated temperature through the hot spot over time for the stationary and moving hot spot. The speeds varied to as great as 20 mm/s, and good agreement was obtained. Furthermore, the sonication images during the real-time test of the sequence in Figure 2 show the moving sonication (at about 13 mm/s) shape appears to agree with the stationary sonication.

In vivo images (Figure 3) demonstrate a mean temperature change of 0.024°C for the left image, with a temperature standard deviation of 1.03°C. In the right image, the mean was 0.021°C with a standard deviation of 1.04°C. Besides phase noise, there are some temperature deviations from blood vessels, however these demonstrate an apparent temperature rise of less than 5 degrees. During an actual sonication, the apparent temperature change in the vessels would be below the temperature range of interest.

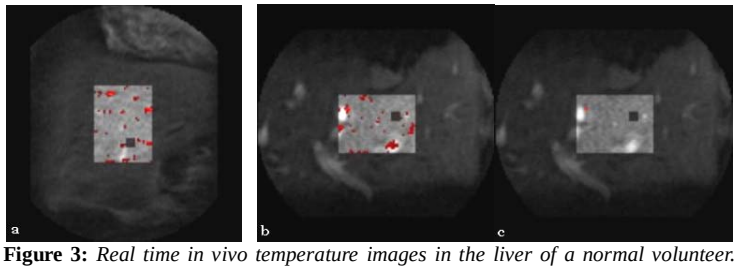


Figure 3: *Real time in vivo temperature images in the liver of a normal volunteer. Temperature overlays in a and b indicate 2-15 ℃, demonstrating the noise level is low. In c, the same frame as b, the color overlay indicates 5-15 ℃, demonstrating the temperature contribution from vessels is negligible in the temperature range of interest. In each, the small square box is the simulated temperature location required for the referenceless processing algorithm.*

Conclusions

We have designed a real time pulse sequence capable of providing accurate temperature maps during simulated respiratory motion. Similarly, the in vivo results demonstrated its suitability for in vivo imaging by demonstrating a zero mean temperature data in a non-heated healthy volunteer. The combined experiments suggest that real time thermometry in the presence of motion can be possible and accurate, and is a promising technique for monitoring HIFU ablations.

Acknowledgements

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References

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