Proceedings of the ASME 2011 Summer Bioengineering Conference
SBC2011
June 22-25, Nemacolin Woodlands Resort, Famington, Pennsylvania, USA

SBC2011-53814

Delineation of noise signals from MRI measured temperature rise during HIFU ablation procedure

Subhashish Dasgupta[1], **Seyed Ahmed Dibaji**[1], **Janaka Wansapura**[3]

Matthew R. Myers[4], **Rupak K. Banerjee**[1,2]

[1]Mechanical Engineering Department
[2]Biomedical Engineering Department
University of Cincinnati, Cincinnati, OH

[3]Imaging Research Center, Cincinnati Children's Hospital Medical Center, Cincinnati, OH

[4]Division of Solid and Fluid Mechanics, Center for Devices and Radiological Health
U. S. Food and Drug Administration, Silver Spring, MD

ABSTRACT

A relatively recent and non invasive method for characterizing thermal fields generated by high intensity focused ultrasound (HIFU) transducers is Magnetic Resonance Interferometry (MRI) Thermometry method. However, noise signals generated by external RF sources infiltrate the scanner orifice and limit its ability to measure temperature rise during the heating or ablation phase. In this study, MRI monitored HIFU ablations are performed on freshly excised porcine liver samples, at varying sonication times, 20, 30 and 40 s at a constant acoustic intensity level of 1244 W/cm^2. Temperature rise during the procedure is measured using Proton Resonant Frequency MR thermometry. Preliminary experiments without an adequate noise filter, failed to record temperature rise during the heating phase. A low pass R-C filter circuit is subsequently incorporated into the experimental set up to prevent infiltration of noise signals in the MRI orifice. This modified RC filter enables measurement of temperature rise during the heating phase followed by temperature decay during cooling. The measured data is within 12% agreement with the temperature rise computed by solving the acoustic and heat equations.

INTRODUCTION

In the preclinical characterization of thermal fields generated by high-intensity focused ultrasound (HIFU) systems, the temperature rise in a tissue phantom or an ex-*vivo* tissue must be accurately measured. The MRI scanner is capable of assessing the transient temperature rise across the treatment volume as well as recording size of the thermal lesions or volume of necrosed tissue(Dasgupta et al [1]).

A potential problem associated with the MRI thermometry method in monitoring thermal therapy is infiltration and interference of noise signals in the scanner orifice causing deterioration of the quality of MRI images. Noise signals are generated during transducer operation by RF sources such as the amplifier as reported by Oshiro et al. [2]. In the present study HIFU ablation is performed and temperature rise is measured using MRI thermometry method using a low pass filter designed to prevent noise infiltration in the scanner. Subsequently, the measurements are validated by computations.

METHODOLOGY

Figure 1 depicts the experimental set up used. The HIFU transducer, H102 (Sonic Concepts Inc.) which has a focal distance of 6.2 cm, radius of 3 cm, and frequency of 1.1 MHz, is positioned vertically and coupled to the excised porcine liver sample via a plexi glass coupling cone. The tip of the cone is placed at selected locations on the liver surface and ablation is performed below the tip. In order to prevent the infiltration of noise signals in the MRI room, a low pass filter circuit (Fig. 2) is incorporated at the amplifier outlet (RF source).

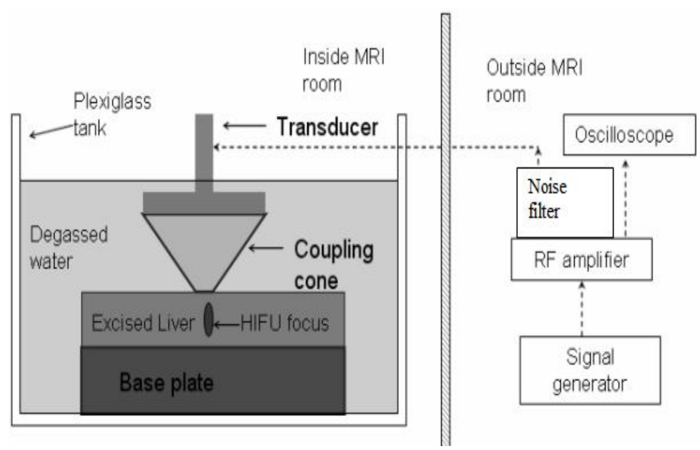

Figure 1: Schematic of experimental set up to access HIFU induced temperature rise in excised liver sample using MRI scanner

The filter employed is an R-C filter, consisting of a 50-ohm resistor and C = 25 pico farad capacitor. The filter is designed such that it is capable of blocking signals above a threshold frequency of 125 MHz, which cause noise disturbances in the scanner.

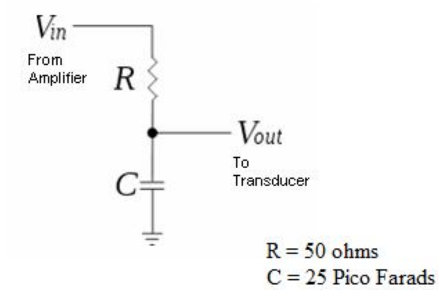

Figure 2: R-C filter circuit for prevention of noise infiltration in MRI scanner

Subsequent to the experiments, numerical calculations, similar to Dasgupta et al. [1], are performed to validate the experimental data. The KZK parabolic wave equation (eq.1) is solved to obtain acoustic pressure, p(r,z), and power deposition rate, Q, is then calculated using $Q = \alpha p^2/\rho_o c_o$, where α is absorption coefficient of tissue. The heat equation (eq. 2) is solved to generate the transient temperature field in the material.

$$\frac{\partial}{\partial t}\left[\frac{\partial p}{\partial z}+\frac{D}{2c_0^3}\frac{\partial^2 p}{\partial t^2}\right]=\frac{c_0}{2}\left(\frac{\partial^2 p}{\partial r^2}+\frac{1}{r}\frac{\partial p}{\partial r}\right) \quad (1)$$

$$\left(\rho_0 c_p\right)\frac{\partial T}{\partial t}=\frac{\partial}{\partial x_j}\left(k\frac{\partial T}{\partial x_j}\right)+Q \quad (2)$$

Here, p is the acoustic pressure amplitude, t is time, c_0 is speed of sound in the tissue (~1540 m/s), D is sound diffusivity, ρ_0 is density (~999 kg/cm^3) and c_p is the specific heat (~3770 J/kg.K).

RESULTS AND DISCUSSION

Figure 3, shows the HIFU induced transient temperature profiles acquired with the low-pass filter. With filtering, temperatures could be acquired during the heating phase with good reproducibility, the standard deviation being about 5 ^{o}C.

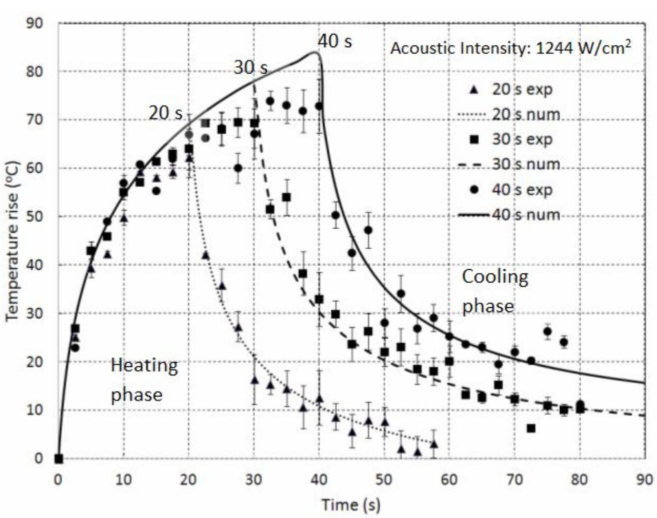

Figure 3: Transient temperature profiles at sonication times 20, 30 and 40 s. Experimental and computational profiles compared.

The experimental temperature rises match the computational ones for approximately the first 10 seconds, but are about 10 degrees lower than the numerical values for the remainder of the heating phase [(84-74)/84×100 = 12% agreement]. During the cooling period, the experimental and computational traces match closely. During the heating phase, low-pass filtering proved effective in reducing external RF noise. Disagreements with numerical predictions are possibly due to the presence of localized boiling (Khokhlova et al [3]). Bubble clouds shield the focal region and reduced the amount of absorbed energy, resulting in a lower temperature rise relative to the theoretical (computational) prediction. The fact that the numerical and experimental values are in close agreement at low temperatures (below the boiling point) confirms the hypothesis of shielding arising due to bubble clouds generated by boiling. It may be noted that the measured absolute peak temperature rise for the 20, 30 and 40 s procedures (Fig. 3) are 85^{o}C (= 62^{o}C of temperature rise + 23^{o}C of presonication tissue temperature), 93^{o}C and 96^{o}C, respectively. Such high temperatures are reported to cause localized bubble formation at the focus of the HIFU beam.

During cooling, filtering resulted in temperature readings that decayed much more rapidly than values acquired in the absence of filtering. Agreement with numerical predictions was much closer for the data acquired in the presence of the low-pass filter, particularly for shorter sonication times.

CONCLUSION

Low-pass filter is an effective tool in reduction of RF noise during experiments to characterize the thermal field of a HIFU transducer. Temperature measurements during the heating phase, which could not be acquired in the absence of the filter, could be obtained reproducibly. These temperatures agreed with computational values to within about 12% which we believe is a reasonable agreement. During the cooling phase, the agreement between computations and experiments was about 10% in the presence of filtering. In the absence of filtering, the experimental temperatures exhibited poor agreement with computations.

ACKNOWLEDGEMENT

This work was funded by the National Science Foundation (Grant No. 0552036).

REFERENCES

1. Dasgupta et al. (2010). HIFU Lesion Volume as a Function of Sonication Time, as Determined by MRI, Histology, and Computations. ASME J. of Biomech. Engg. 132.
2. Oshiro et al. (2006) Reduction of Electronic Noise From Radiofrequency Generator During Radiofrequency Ablation in Interventional MRI. J. of Comp. Asst. Tomography, 26 308-316.
3. Khokhlova et al. (2006). Effects of nonlinear propagation, cavitation, and boiling in lesion formation by high intensity focused ultrasound in a gel phantom. Journal of Acoustical Society of America, 119, 1834–1848.