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TEMPERATURE RISE IN TISSUE MIMICKING MATERIAL DURING HIFU PROCEDURES

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ABSTRACT

High Intensity Focused Ultrasound (HIFU) has shown considerable promise as a minimally-invasive technique for various therapeutic applications such as tumor ablation and vessel cauterization. The efficacies of these HIFU procedures depend on various operational parameters such as total acoustic power, pulse duration and transducer dimensions. In this study, the effect of total acoustic power on the tissue temperature rise is studied both experimentally and numerically. Experimentally, HIFU ablations, at different acoustic powers, were carried out in a tissue mimicking material embedded with thermocouples. Temperature rise measured from the *in-vitro* experiments were then validated with the numerical computations. Results show that experimental and numerical temperature rise match accurately. Our numerical model was able to predict the peak temperature rise within ~12% of the experimental results. Results also show that the tissue temperature rise is linearly proportional to the input acoustic power. For the acoustic power levels considered in this study, the results suggest that acoustic non-linearity does not play a major role on the tumor ablation procedure.

INTRODUCTION

A typical HIFU procedure involves focusing of acoustic energy in a small region, with the absorbed acoustic energy causing localized rise in tissue temperature. Temperature rise of the order of 40-60^{o}C is achieved within few seconds, causing immediate cell necrosis in the targeted region. The efficacy of a HIFU procedure depends on operational parameters such as total acoustic power, pulse duration and transducer dimensions. Hariharan et al. [1] numerically evaluated the influence of pulse duration and transducer dimensions on the efficacy of HIFU procedures. The main objective of this study is to evaluate, both experimentally and numerically, the dependence of tissue temperature rise on the input acoustic power.

METHODOLOGY

The HIFU sonications were performed on a hydrogel based tissue-mimicking material [2] for which the thermal properties like specific heat and conductivity and acoustic properties like acoustic absorption closely matched those of the actual tissue. Thin wire Copper-constantine thermocouples were embedded in the tissue mimicking material. Figure 1A shows the schematic of the experimental setup. The focus of the transducer was made to coincide with the location of the thermocouple junction (Fig 1 B), within the material. The power level was varied from 5W to 25W. The transient temperature rise was recorded at each power

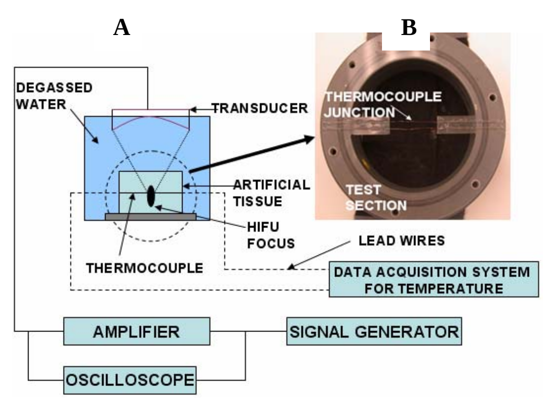

Figure 1A: Schematic diagram of HIFU apparatus
B: Test section before filling the tissue mimicking material

level. The experiments were repeated thrice to confirm reproducibility of results.

Numerical calculations were done to validate the experimental data. The model solved the linear form of KZK parabolic wave equation for axisymmetric sound beam propagation in Z direction (eq.1) and the heat equation (eq. 2). The wave equation solved the acoustic pressure p(r,z) and power deposition rate Q was calculated from the relation $Q = 2\alpha p^2/2\rho c$, where α is absorption coefficient of tissue. The heat equation generated the transient temperature field in the material.

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

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

Here p is the acoustic pressure, t is time, c_0 is speed of sound in the material~1540 m/s, D is sound diffusivity, ρ is density ~999 kg/cm^3 and c_p is the specific heat~3770 J/kgK.

RESULTS AND DISCUSSIONS

Figure 2 compares time trace of temperature rise obtained experimentally and numerically in tissue mimicking material for different input acoustic powers ranging from 5-25W. Figure 2 shows that the tissue temperature rises linearly for the first few seconds and then gradually till the ultrasound is turned off after 20s. This temperature rise curve is typical of HIFU procedures. In addition, no abrupt rise in temperature was observed experimentally suggesting the absence of cavitation [3]. Figure 3 shows peak temperature rise as a function of input acoustic power obtained experimentally and numerically. For the acoustic power levels considered in this study, the peak temperature rise was found to increase linearly with acoustic power (Fig 3). This linear rise indicates the absence of strong non linear propagation effects such as shock formation. At 5W, 17W and 25W the peak temperature rise was measured as 8^0C, 30^0C and 40^0C respectively. The temperature rise calculated numerically deviated from the experimental measurements by 8% for 5W and 17W, and 12% for 25W. This discrepancy is likely due to the mismatch between the thermocouple location and the HIFU focus.

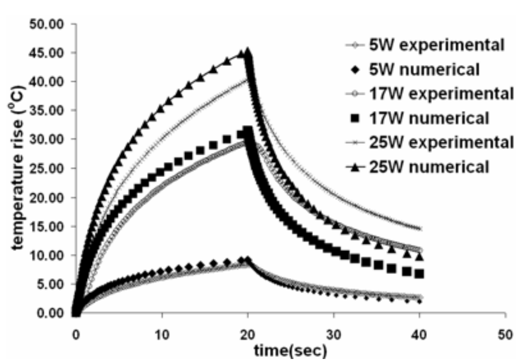

Figure 2: Temperature profiles at different acoustic power levels

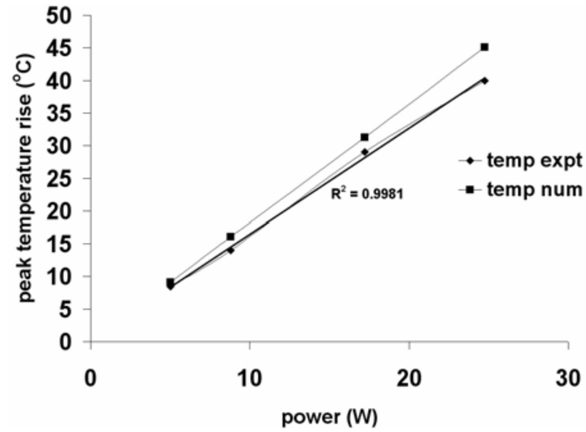

Figure 3: Peak temperature rise as a function of acoustic input power

Consequently, the results suggest that for the power levels considered in this study, tissue temperature rise at the HIFU focus is linearly dependant on the input acoustic power. Accordingly, the size of the ablated zone in the tissue will be dependant on the input acoustic power.

CONCLUSION

It can be concluded that input power of the transducer is an important operational parameter, which significantly influences peak temperature rise of the tissue mimicking material. A linear rise of peak temperature with increasing power level was experimentally recorded for the chosen power levels. The finding was confirmed by the results of numerical calculations. Consequently, we see that acoustic nonlinearity is not important upto an acoustic power level of 25W. In future, experiments will be carried out at higher power levels to evaluate the dependence of tissue temperature rise on acoustic non-linearity. In addition, influence of cavitation on lesion formation process can be studied.

ACKNOWLEDGEMENT

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