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INFLUENCE OF THE TRANSDUCER ACOUSTIC POWER ON FOCAL LOCATION OF THE BEAM DURING HIFU ABLATION PROCEDURE

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ABSTRACT

The location of High Intensity Focused Ultrasound (HIFU) beam in a tissue medium is an important parameter in assessment of the thermal field as it influences the temperature rise in the tissue. Our *hypothesis* is that the location of the beam can be affected by the power of the transducer. HIFU procedure with 30s of sonication time was performed at different powers of transducer (5 to 60 W) as well as different initial locations of beam in a tissue mimicking material. Eight thermocouples were embedded at 4 different layers in a phantom to measure the temperature rise during HIFU procedure. An inverse method based on experimental data and optimization algorithm was used to find the actual location of beam based on the experimental data. Our experimental data showed that for a higher power (60 W) as compared to a lower power (5 W), the focal distance that the actual position of beam moves away from its initial location increased with the raise in power. Thus, beam location can change at different powers of transducer. Using inverse method we showed that there is a direct linear correlation ($R^2 = 0.95$) between the transducer power and the distance that beam moves away from its initial location. Therefore, it is of great clinical importance to study the effects of transducer power on the location of HIFU beam in an attempt to minimize the damage to healthy cells.

INTRODUCTION

High-intensity focused ultrasound (HIFU) is an invasive medical procedure during which a large amount of energy is deposited in a short duration which causes sudden localized rise in tissue temperature, and ultimately, cell necrosis. Consequently, location of the HIFU beam in a tissue medium is an important parameter as it influences the temperature rise in the tissue [1]. Thus, it is of great clinical importance to know the exact location of HIFU beam for minimizing excessive or collateral tissue damage.

In vitro experiments on tissue mimicking material with embedded thermocouples have been widely employed as a pre-clinical method to evaluate the focusing characteristics of HIFU beam and the corresponding thermal field [2]. Although the temperature rise during HIFU procedure in a phantom has been studied extensively in previous work, not much is reported regarding the effect of parameters such as transducer power on the location of HIFU beam. The *hypothesis* is that HIFU beam location can be affected by the power of transducer. Recently, we developed an inverse method to find the location of HIFU beam within a tissue mimicking material [3]. In this study, we employed this method along with our experimental data to assess the effect of transducer power on the location of HIFU beam.

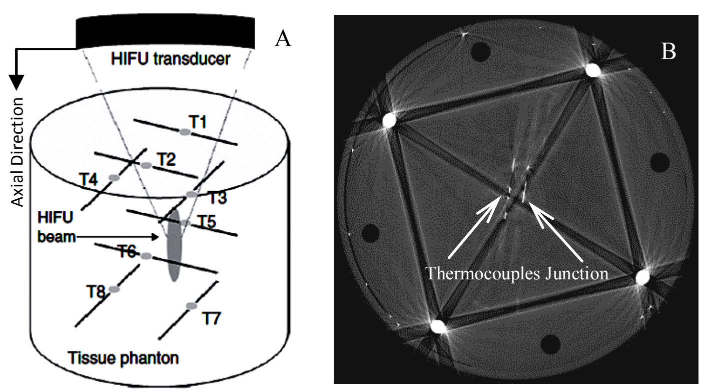

Figure 1. (A) Experimental schematic showing phantom and arrangement of thermocouples. (B) Thermocouples junction in CT-scan.

METHODS

Experimental Setup. HIFU procedure was performed on a phantom similar to our previous studies [1, 3]. The HIFU transducer was 1.1 MHz with focal length of 6.26 cm. Eight thermocouples (T1, T2,… T8) were placed in 4 layers (Fig. 1A). Thus, each layer, staggered by 90º, had two thermocouples that were parallel to each other. First T3 junction was found to be located at the position of highest temperature rise as the beam was moved along the phantom in the plane of T3 and T4. After finding T3 junction, CT-scan was used to find the relative location of other thermocouples junctions in phantom (Fig. 1B). Knowing the location of thermocouple junctions, HIFU beam can be positioned within the junctions in the phantom. The experiment was done for five different beam locations in the plane of T3 and T4, namely as L0: middle of T3 and T4, L1: 0.25 mm toward T3 from the middle, L2: 0.5 mm toward T4 from the middle, L3: 0.75 mm toward T3 from the middle and L4: 1 mm toward T4 from the middle of T3 and T4. Transducer acoustic powers of 5, 10, 20, 30, 40, 50 and 60W were used at each location. Sonication time and cooling period were 30s each. The phantom temperature was recorded using an OMB-DAQ-56 data acquisition system.

Inverse Method. Because of possible uncertainty in the position of the beam, an inverse method was used to find the actual position of the beam in the phantom for each power for locations L0 to L4. Based on an initial guess for the beam location, phantom temperature was numerically calculated (T_{num}) at thermocouples. The optimization error metric between the measured temperature (T_{exp}) and the computed temperature (T_{num}) corresponding to the assumed beam location was calculated. The optimization algorithm refined the beam location using the Nelder-Mead scheme. More detail on inverse method is given in our previous work [3].

RESULTS

Effect of Transducer Acoustic Power on the Location of Beam; Experimental Data. In order to assess the effect of transducer power on the location of beam, phantom temperature at T4 and T8 for two powers of 5 and 60 W are shown in Fig. 2.

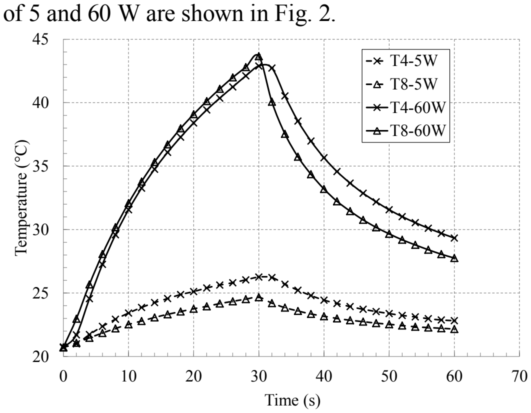

Figure 2. Phantom temperature at T4 and T8 for two transducer powers of 5 and 60 W. HIFU beam was located at L4.

HIFU beam was located at L4. T8 was located 5.60 mm lower than the plane of T3 and T4 in axial direction. At the power of 5 W, phantom temperature after 30s sonication was 26.26 ± 0.02 °C for T4, while being 24.7 ± 0.1 °C for T8. However, phantom temperatures for T4 and T8 at the power of 60 W after 30s sonication were 42.9 ± 0.1 °C and 43.7 ± 0.1 °C, respectively. Thus, higher temperature was obtained by increasing the transducer power. At the power of 5 W, phantom temperature was higher at T4 in comparison to T8, as beam was placed closer to T4. However, as power increased to 60 W, temperature at T8 was higher than T4, though the HIFU beam was initially located closer to T4. This shows that the location of HIFU beam has changed in axial direction and has become closer to T8 by increasing the transducer power to 60 W.

Finding the Location of Beam Using Inverse Method. As shown in our experimental data, location of HIFU beam can change from its initial position by increasing the transducer power. Inverse method was employed to find the actual position of beam in the axial direction for different transducer powers ranged from 5 to 60 W (Fig.3). HIFU beam was initially located at L0 to L4, which are described in the methods section. It should be noted that in the inverse method, middle of T5 and T6 was considered as the initial guess for the location of HIFU beam. The actual position of beam in axial direction was found with respect to the transducer face. At the power of 5 W, the actual position of beam was found to be 63.15 ± 0.96 mm from the transducer face. By increasing the transducer power, location of the beam was found to be 63.18 ± 1.07, 66.12 ± 1.12, 67.05 ± 1.17, 68.44 ± 0.90, 69.17 ± 0.83, and 69.77 ± 0.9 mm from the transducer face for acoustic powers of 10, 20, 30, 40, 50, and 60 W, respectively. A direct linear correlation (R^2 = 0.95) was found between the transducer power and change in axial position of beam. Thus, the focal distance that the actual position of beam moves away from its initial location increased with the raise in power.

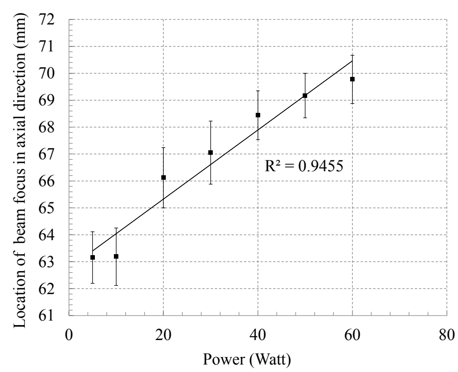

Figure 3. Actual location of HIFU beam in axial direction for different transducer powers using inverse method.

CONCLUSIONS

Using experimental data of HIFU procedure on a phantom, we showed that the initial location of HIFU beam changes at different transducer powers. Accordingly, in order to find the actual location of beam, an inverse method was employed to find the actual location of beam in axial direction for different powers of transducer. A direct linear correlation (R^2 = 0.95) was found between the transducer power and the distance in axial direction that the beam moves away from its initial location. Thus, from clinical prospective, it is of great importance to find the effect of transducer power on the location of beam during a HIFU procedure which can minimize the risk of damage to healthy tissues.

ACKNOWLEDGEMENTS

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