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An Experimental Study of Effects of Overlaying Tissues on HIFU Lesion

Tao Long^{1,2}, Viren Amin^{1,2}, Ronald Roberts¹, R.B. Thompson¹,
Scott McClure³, Timothy Ryken⁴

¹Center for Nondestructive Evaluation, ²Department of Electrical and Computer Engineering and

³Department of Veterinary Clinical Sciences, Iowa State University, Ames, Iowa, USA

⁴Department of Neurosurgery and Radiation Oncology, University of Iowa, Iowa City, Iowa USA

Abstract. Understanding the effect of overlaying tissues on HIFU lesion is crucial for estimating HIFU dose distribution at a target tissue. We have run a series of experiments to systematically observe the effects of the overlaying tissues on the HIFU beam and ultimately the lesion created in the target tissue. First, we mapped out the HIFU transducer beam (in low power) under water without and with different overlaying tissue layers. Then, we performed a series of experiments in high power to create lesions in target tissues (e.g., liver) without and with overlaying tissues (e.g. muscle). The lesions are characterized by slicing the tissues and reconstructing the 3D lesion from calibrated pictures of the target tissue slices. The low power beam measurements show significant effects in terms of severe beam wave-field amplitude distortion due to phase aberration introduced by velocity inhomogeneity in the overlaying tissues. These results compare well qualitatively with the computational models. The results from the high power HIFU lesions in a similar setup using various tissues, including liver and muscle, provide understanding of the significance of phase aberration in overlaying tissues and could prove useful towards high precision HIFU therapy.

Keywords: HIFU, overlaying tissues, lesion characterization, lesion 3D construction

PACS: 43.64.+r

INTRODUCTION

High-intensity focused ultrasound (HIFU) has its potential in tumor treatment due to its non-invasive nature, as compared to commonly used treatments such as surgery, chemotherapy and radiation therapy. Before HIFU energy is delivered to the focus, the HIFU beam has to go through a number of overlaying tissues. Thus understanding the effects of overlaying tissues on HIFU beam is necessary for precise and accurate lesion creation in the target area. We presented our initial work on simulation models as well as beam profile mapping through different layers of tissues *in vitro*, measured in low power mode [1] to study the effect of phase aberration caused by inhomogeneity within tissues. Compared qualitatively, phase aberration caused by tissue inhomogeneity was similar in simulation model and experimental results. To further study the effects of overlaying tissues, we continue our work by creating lesions in high power mode through different overlaying tissues/thicknesses. Lesions are then characterized in terms of its volume and shape. Such characterization of

lesions is compared to our results found in simulation and low power mode. We present our initial results of such comparisons and effects of overlaying tissues.

METHODS AND MATERIALS

We divide our overall experiment descriptions into three sections: HIFU system setup, tissue handling and image processing and 3D construction.

HIFU system setup

We use a HP 8166A function/pulse generator to generate continuous sinusoidal waveforms at 1.561 MHz (third harmonic frequency of the HIFU transducer we used). The waveforms are then amplified through a 50dB power amplifier. Amplified waveforms then go through an electrical impedance matching box and drive the HIFU transducer.

The transducer we use has 64 mm active diameter and 62.64mm geometric focal length. We position the HIFU transducer so that it faces directly to the target tissue through different overlaying tissues. During our experiment, the electrical power output to the HIFU transducer is about 80 watts. According to HIFU transducer's manufacturer's specification and our measurement in low power mode in water, the dosage at the focus in water is about 3.38 watts per cubic millimeters. Figure 1 shows our HIFU system set up in our experiments.

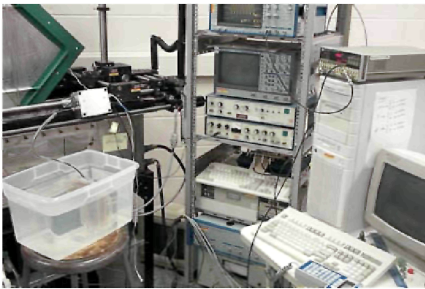


FIGURE 1 HIFU system setup



FIGURE 2 Tissues in gelatin block

Tissue Handling

For lesion creation, we use bovine liver as our target tissue and bovine liver, porcine muscle tissue and chicken muscle tissue as our overlaying tissues. For each overlaying tissue, we have two different thicknesses, namely 0.5cm and 1.0cm. For each overlaying tissue/thickness combination, we have two exposure durations, namely 20 seconds and 30 seconds. With four lesions for each configuration, there are totally 48 lesions created for our study.

To facilitate handling of soft tissues and ensure consistent tissue thickness and positioning during our experiment, we embed our layers of tissues in gelatin

(14.3 g of dry gelatin powder in 237 ml of water), shown in Figure 2. A typical tissue handling procedure begins with embedding tissues in gelatin, then exposed to HIFU for lesion creation. Gelatin embedded tissues with lesions are then frozen with dry ice. Once the tissues harden, they are cut into thin slices with 2.5mm thickness. These slices showing lesions in cross sections are then positioned on grid paper for image processing.

Image Processing and 3D construction

Such slices are then digitally photographed with precise calibration. Lesions in each digital image of the slices are then segmented by tracing out the boundary of the lesions, shown in Figure 4. Typically, there are about 4 to 10 slices for each lesion, depending on the lesion's shape and size. We use visualization software we develop to construct 3D models of the lesions and perform volume calculation based on our calibration. To see how accurate we can calculate the volume through such procedures from embedding in gelatin to 3D construction, we apply these procedures to calculate the volume of three chicken eggs with pre-measured volume. Our experiments show there is about 4% to 8% error for volume calculation using such procedures.

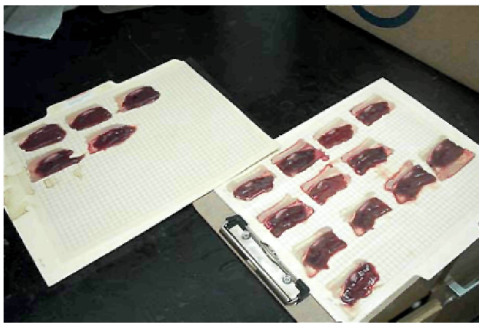


FIGURE 3 slices of layers of tissues

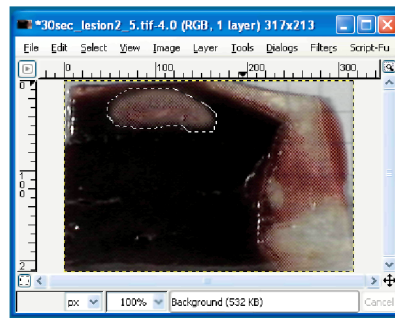


FIGURE 4 segmentation of lesion

RESULTS AND DISCUSSION

We discuss our results in terms lesions shapes through 3D construction and lesion volume comparison.

Lesion Shapes

The first row of Figure 5 shows the typical lesion reconstructions for lesions created in bovine liver tissue through 1cm of bovine liver, porcine muscle and chicken muscle tissue respectively. The 3D models are oriented such that the HIFU transducer is position at the top facing downward.

The second row of Figure 5 shows corresponding center slices used for 3D construction. The slices are segmented with the lesion boundary traced out.

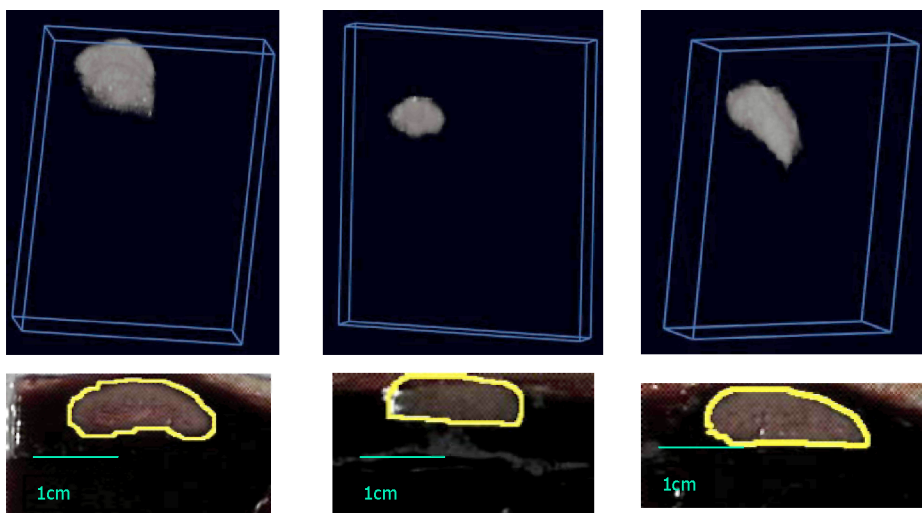


FIGURE 5 The first row shows 3D construction from segmented slices for lesions created through 1.0cm of bovine liver tissue, porcine muscle tissue and chicken muscle tissue; the second row shows the center slice of the segmented lesion.

Based on our observation, the lesions through different overlaying tissues/thickness are similar in shape (bean shaped) although vary in volume. Compared to simulation and our experiments in low power mode [1], the effects of phase aberration caused by tissue inhomogeneity are not as obvious as one would guess.

Lesion Volume Comparison

Table 1 shows average volumes (in cubic millimeters) in different configurations based on 4 samples for each configuration.

TABLE 1. Average Lesion Volumes in cubic millimeters based on 4 samples per configuration				
	0.5cm thickness 20sec duration	0.5cm thickness 30sec duration	1.0cm thickness 20sec duration	1.0cm thickness 30sec duration
Bovine Liver	623.6	1660	285	303
Porcine Muscle	489	805	160	393
Chicken Muscle	708	875	233	351

As observed from the table above, the thinner the overlaying tissue is and the longer the HIFU exposure is, the larger the lesion is for the three types of overlaying tissues. Lesions created through bovine liver tissue also show larger lesion volumes as compared those through chicken muscle tissue and porcine muscle tissue, which suggests there is less attenuation and scattering effects in bovine tissue as compared to the other two.

In our experiment, we also observed more significant shifting in bovine liver tissues toward the HIFU transducer during our experiments.

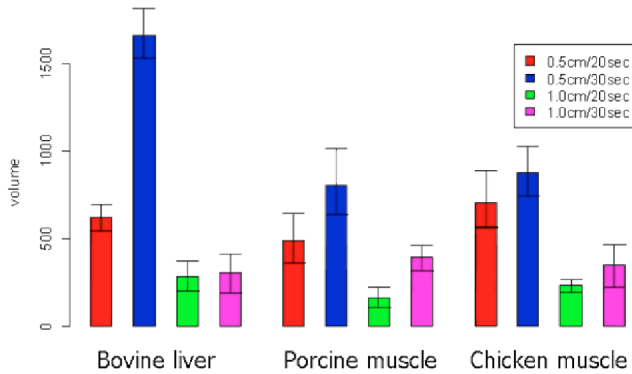


FIGURE 6. Bar plot of lesion volumes with 1 standard deviation bars

CONCLUSION AND FUTURE WORK

We present our initial results on effects of overlaying tissues on lesions shape and volume. The effects of phase aberration in simulation as well as measured in low power mode are not as obvious in our experiments in high power mode, as observed from lesion shapes. Different lesion volumes due to different overlaying tissue/thickness/HIFU duration were also compared.

Future work includes: characterization of lesions and the growth of lesion in real-time through ultrasonic imaging, experiment with more complex geometry of overlaying tissues and modeling temperature rise at and around HIFU focus and validation with experimental results.

ACKNOWLEDGMENTS

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