TRANSMISSION ULTRASOUND IMAGING TO GUIDE THERMAL THERAPY

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Abstract- **Thermal therapy is a technique that can locally destroy tumours by heating them to 55 °C and higher. Transmission ultrasound can detect the treatment induced changes in tissue attenuation. During thermal therapies, an increase in temperature reduces tissue attenuation while changes in tissue structure due to coagulation increases tissue attenuation. In this paper, we investigate the use of a transmission ultrasound camera (AcoustoCam, Imperium Inc., Silver Spring, MD) to quantitatively measure changes in attenuation and monitor in real-time the effect of thermal therapy. To calibrate the ultrasound camera, tissue-mimicking phantoms (10) with different attenuation values ranging from 3 dB to 30 dB were constructed. Frequency-dependent attenuation coefficients were calculated over a frequency range of 3.5 MHz to 7.5 MHz in steps of 0.5 MHz using an independent technique. These phantoms were then imaged using the AcoustoCam and the corresponding mean pixel intensities were obtained. The relationship between average pixel intensity and attenuation value was established. A temperature sensitive phantom was made and heated using a laser fiber. The laser fiber was a 2-cm long cylindrical diffuser (Photoglow, Yarmouth, MA). One image per second was taken during the heating procedure for 20 minutes. The difference in pixel intensity prior to and after heating due to the formation of a lesion was measured and related to the attenuation value change from the calibration curves. It was found that the attenuation changed by 4 dB (0.33 dB/cm) close to the phantom. The results obtained show the reliability of using transmission ultrasound in monitoring thermal therapy which was sensitive to changes as small as 0.08 dB in the PVCP phantom experiment.**

I. INTRODUCTION

Minimally Invasive Thermal Therapy (MITT) is an effective way to destroy diseased tissue and could replace a surgery or radiation therapy. During MITT, high temperatures in the range of 55 °C to 100 °C are produced locally in the target tissue or tumour. This will ultimately result in tumour coagulation [13].

In MITT a real-time monitoring method is required to prevent the nearby healthy tissue from damage while treating the diseased tissue. Real-time monitoring could also detect the variations in size and shape of the thermal lesion to ensure it covers the entire tumor. Several modalities are being explored, including Magnetic Resonance Imaging [14] and Computed Tomography [3, 4]. For the modality to have a strong clinical impact cost, availability and procedure complexity also become important attributes. Moreover, to monitor a thermal therapy treatment, it is likely that the imaging method of choice will be selected based on its' sensitivity to the detection of specific mechanisms of tissue damage.

Acoustic attenuation is known to change during the formation of lesions. A general increase in attenuation was observed at temperatures of 55 °C or greater in in-vitro samples of porcine kidney [15]. The change in attenuation coefficient with rising temperature shows different trends in different tissues [12]. Therefore, an imaging technique that is sensitive to ultrasound attenuation changes may be used to monitor thermal therapy treatments. Transmission ultrasound imaging is a non-invasive imaging modality which could be used in an image-guided thermal therapy procedure to monitor the heating.

In this paper the feasibility of a transmission ultrasound camera called AcoustoCam (Imperium Inc., Silver Spring, MD) for an image-guided thermal therapy has been investigated. The usability of AcoustoCam in thermal therapy monitoring was first investigated by King et al. [8]. Recently Parmar and Kolios investigated the use of this technique in a qualitative manner [10]. This paper is a continuation of this work on how the attenuation of the target tissue during thermal therapy is quantitatively related to changes in pixel intensity of the AcoustoCam images.

In this paper, tissue equivalent materials of known attenuation were used to relate pixel value to attenuation. The attenuation values for the tissue equivalent materials (tissue phantoms) were independently measured using standard ultrasonic techniques, without relying on assumed values based on formulas that take into account the different phantom constituents. This is important as there is variability in attenuation values of similarly constructed phantoms between different labs.

II. METHODS

The AcoustoCam developed by Imperium Inc. is a transmission ultrasound camera which was used in this study to collect transmission ultrasound images. It replaces the lens, aperture and sensors of an optical charge couple device (CCD) camera with acoustic counterparts. The receiving part of the camera consists of two parts, an acoustic compound lens consisting of a pair of lenses and a PE-CMOS sensor array which is a piezoelectric material deposited onto a CMOS sensor array. The attenuated pressure wave is focused onto the sensing array by the two lenses. The array is made up of 120×120 (14,400) pixel elements. The ultrasound energy that strikes the array is captured by a frame grabber installed on a PC [9]. Figure 1 shows the AcoustoCam setup. The whole setup is placed in degassed and deionized water.

Figure 1. AcoustoCam setup with the transducer, phantom and camera highlighted.

The transducer used in the AcoustoCam system is a 4.76 MHz planar transducer which illuminates the target tissue that is placed between the transducer and the camera. The experiments are conducted in a tank filled with degassed and deionized water. Images are recorded via a RS-232 video stream at a rate of 30 frames/second. The images viewed on the screen are 8-bit images, i.e. 256 different gray levels. Figure 2 shows an acoustic image of a finger which was taken with the AcoustoCam. The higher the ultrasound attenuation, the darker the pixel intensity appears on the screen.

Our proposed methodology is validated by measurements on a number of homogeneous tissue-equivalent phantoms which were constructed to mimic tissue attenuation properties. The first set of phantoms made with PVCP (Poly Vinyl Chloride Plastisol) included 10 phantoms with different thicknesses to simulate different attenuation values (Table 1). PVCP phantoms were used to obtain the calibration curves for the AcoustoCam, while a temperature-sensitive albumen phantom [7] was used to perform a heating experiment.

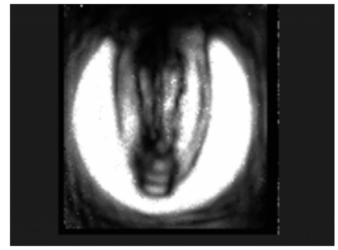

Figure 2. Acoustic image the finger of the author taken with AcoustoCam. Several structures such as the bone and nail can be distinguished

A. <u>Calibration of the AcoustoCam</u>

PVCP (M-F Manufacturing Co., Fort Worth, Texas, USA) is a non-toxic oil-based plastic that solidifies upon heating to high temperatures around 200℃ and cooling. After cooling, it can easily be removed from the mold. A set of 10 PVCP phantoms were constructed. Varying the phantom thickness, different attenuation values ranging from 2 dB to 26 dB were achieved. The attenuation coefficient for PVCP was measured *independently* by utilizing two focused transducers with a centre frequency of 5MHz as a transmitter and receiver pair [11].

The phantoms were imaged using the acoustic camera. The software permits the user to operate the AcoustoCam through an intuitive Graphical User Interface. The Matlab Image Processing Toolbox (Mathworks, Inc.) was used to obtain the 8-bit average pixel intensity of each phantom's acoustic image. The 8-bit intensity were then graphed against the corresponding attenuation values for all the phantoms.

B. <u>Heating Experiment</u>

The albumen phantom constructed and used in our heating experiment is a temperature-sensitive homogeneous phantom which consists of chicken egg albumen, agar and Naphtol Green dye [7]. It has similar properties to tissue in that it undergoes a visible irreversible whitening effect as a result of thermal coagulation. To heat the albumen phantom, a laser fiber was inserted into the phantom through the small hole on top of the phantom- containing mold. The laser fiber was a 2-cm long cylindrical diffuser (Photoglow, Yarmouth, MA). The phantom was locally heated for 20 minutes and an image was recorded using the AcoustoCam each second. After the heating was stopped, an image was taken for another 180 seconds to observe the effect of cooling on the acoustic image of the lesion. The average pixel intensity of each image was measured and graphed versus time. The calibration curves obtained in the calibration procedure were used to get the relevant attenuation-time graph.

A similar albumen phantom was constructed and heated in an 80 °C water bath for 60 minutes. The 8-bit mean pixel intensity as well as the 14-bit mean pixel intensity was recorded to see how the attenuation value varies between the coagulated and non-coagulated phantoms.

III. RESULTS

A. PVCP Phantoms and Calibration of the AcoustoCam

The attenuation values of the constructed PVCP phantoms which were measured according to the *independent* attenuation measurement are listed in table 1. The attenuation values for the phantoms are estimated at 4.76 MHz which is the centre frequency of the transducer used with the AcoustoCam. The AcoustoCam setup was then used to image the phantoms.

TABLE 1. Calculated attenuation values for PVCP phantoms with the independent method. Errors for the attenuation represent the standard deviation of 5 separate measurements.

Phantom	Thickness [cm]	Attenuation [dB] @ 4.76MHz
Phantom A	0.52 ±0.05	2.2 ±0.03
Phantom B	1.17 ±0.05	4.9 ±0.03
Phantom C	1.71 ±0.05	7.1 ±0.20
Phantom D	2.42 ±0.05	10.1 ±0.03
Phantom E	3.07 ±0.05	12.8 ±0.05
Phantom F	3.72 ±0.05	15.6 ±0.06
Phantom G	4.30 ±0.05	18.0 ±0.06
Phantom H	4.93 ±0.05	20.6 ±0.04
Phantom I	5.45 ±0.05	22.8 ±0.02
Phantom J	6.30 ±0.05	26.3 ±0.1

The 8-bit pixel intensities of the acquired scans were obtained and graphed against the corresponding attenuation values for all the phantoms. 14-bit data were also acquired (data not shown) to provide greater dynamic range in the measurement. Figure 3 shows how the 8-bit average pixel intensities change as the attenuation value increases. Figure 4 shows the pixel intensity variation for a 2.2 dB-26.3 dB range of attenuation.

B. Albumen Phantom and the Heating Experiment

The albumen phantom was constructed and used for the laser heating experiment [7]. The phantom was heated with the laser locally for 20 minutes to make sure that a temperature of 80 °C is reached. An image was recorded in one second intervals and the 8-bit average pixel intensity was measured and graphed versus time across three regions starting from adjacent to the laser fiber as shown in figure 5.

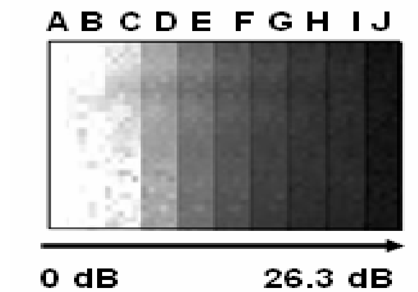

Figure 3. Shows how pixel intensities vary in an attenuation range of 2.2 dB to 26.3 dB

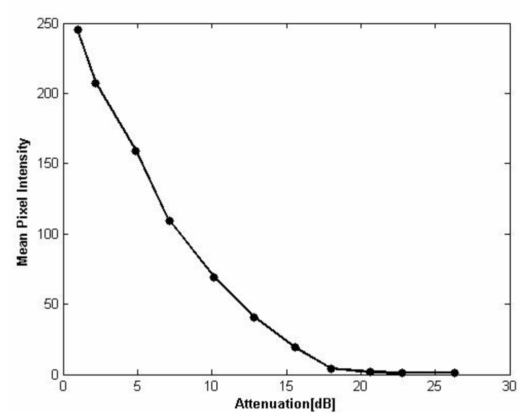

Figure 4. The change of 8-bit average pixel intensities according to the attenuation values.

Figure 6 shows the change of the acoustic attenuation as a function of time across three regions specified in figure 5. The corresponding attenuation values were calculated and plotted as a function of time. It can be seen that a slight initial decline in attenuation value is followed by an attenuation increase. The total attenuation increase is 2.8 dB for the first region, 4.1 dB for the second region and 6.0 dB for the third region. The change in attenuation is highest close to the laser fiber and decreases with radial distance. Cutting open the albumen phantom along where the laser fiber was placed, a symmetrical cone-shaped lesion was measured. The attenuation increase in the albumen phantom heated in the 80 °C water bath was 4 dB (1.33 dB/cm).

IV. DISCUSSION AND CONCLUSIONS

Several observations could be made in the procedure of the AcoustoCam calibration. Figure 3 shows the PVCP phantom acoustic images and illustrates how acoustic attenuation can be expressed in terms of pixel intensity levels.

It can easily be seen that higher attenuation values result in darker pixel intensities which means that the ultrasound energy captured by AcoustoCam's sensor array decreased.

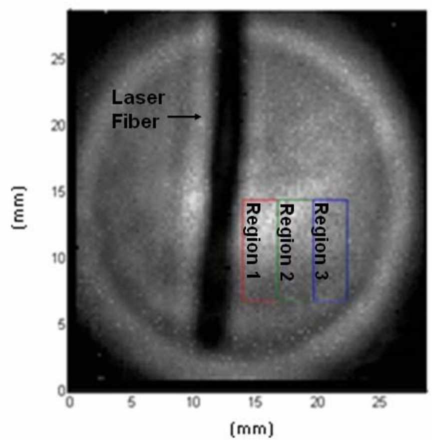

Figure 5. The acoustic image of an albumen phantom. The laser fiber was used to heat the phantom locally.

For the attenuation range of 0 dB-20 dB a pixel intensity variation of 245 could be detected. For attenuation values above 20dB, no significant effects regarding pixel intensity could be observed (Figure 4). It was calculated that according to the 14-bit AcoustoCam's output, the AcoustoCam has the capability of detecting attenuation differences as small as 0.08 dB.

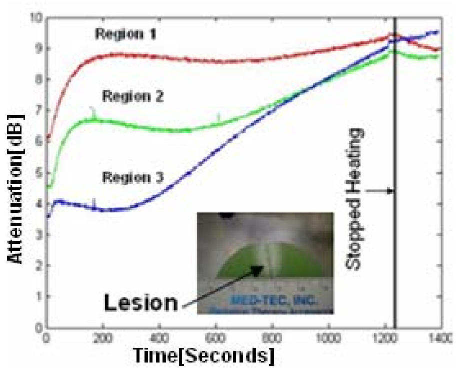

Figure 6. Acoustic attenuation change upon heating.

Tissue coagulation due to laser heating resulted in a symmetrical cone-shaped lesion formation. The average pixel intensities of the albumen phantom acoustic images were measured across three regions specified on figure 5 and shown in figure 6.

An attenuation increase of 4 dB (1.33 dB/cm) could be detected after heating the albumen phantom in the 80 °C water bath and is consistent with the laser heating results.

These measurements represent the complex change in attenuation that occurs in thermal therapy: while the phantom coagulation increases the ultrasound attenuation, increased temperatures results in attenuation decrease [12]. A series of experiments to better understand the dynamic changes in ultrasound attenuation during thermal therapies is currently underway.

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