2P-46

Proceedings of Symposium on Ultrasonic Electronics, Vol. 31 (2010) pp. 381-382
6-8 December, 2010

Study on Change in Sound Speed by HIFU-Exposure in Chicken Breast Muscle

強力集束超音波(HIFU)を照射された鶏ささみ肉の音速測定

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1. Introduction

Ultrasound echography is known well as a non-invasive and real-time monitoring method and widely used in clinical sites to evaluate the tissue properties inside the body. The image is closely related to acoustic properties such as acoustic impedance, sound speed and absorption. Thus, if acoustic properties are significantly changed according to a tissue state, the tissue states should be able to be identified by ultrasound echography.

High-intensity focused ultrasound (HIFU) is able to produce high temperature at a focal point with no direct contact, and is applied to medical treatment to necrose a tumor cells due to rise in heat.

In order to ensure the safety of the treatment, the states of the tissue before, during, and after HIFU treatment should be monitored by a non-invasive method. If acoustic properties of HIFU-exposed biological tissue significantly vary with the state of the tissue, a conventional method of ultrasound echography may be used to monitor the HIFU treatment.

It is known that the sound speed and attenuation of tissues change depending on their temperature [1, 2]. It was reported that the attenuation of biological tissue was increased by thermally denaturation but the sound speed was not changed.

Previously, we reported that the acoustic impedance of HIFU-exposed chicken breast muscle was significantly decreased after thermal denaturation [3]. Although this suggests decrease in the density or the sound speed, it has not been clarified.

In this study, we measure the sound speed of thermally denatured and non-denatured portions of HIFU-exposed chicken breast muscle to investigate the cause of the change in the acoustic impedance.

2. Experimental Setup

2.1 HIFU-Exposure

Chicken breast muscle was used as the specimen. It was commercially obtained. **Figure 1** shows a schematic diagram of HIFU exposure. It was performed in degassed water at about 37°C. A spherical concaved transducer was used to generate HIFU waves. The transducer has a resonance frequency of 1.14 MHz, a focal length of 70 mm, and an aperture diameter of 70 mm. A specimen was set on the focal point of the transducer and exposed to HIFU at about 800 W/cm^2 for 60 s. Five pieces of HIFU-exposed specimen were prepared.

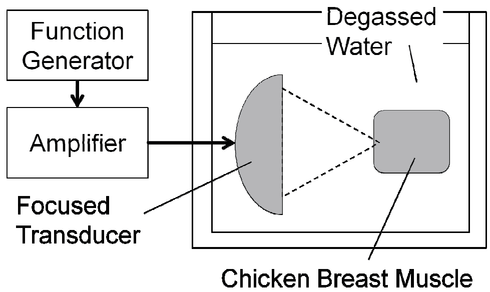

Fig. 1. Schematic diagram of HIFU-exposure.

2.2 Sound Speed Measurement

Sound speed was measured by a pulse-echo method [4, 5]. **Figure 2** shows the experimental setup of the sound speed measurement. The measurement was performed in saline solution. Its temperature was kept at (36.0 ± 0.5)°C using a thermostat bath. Ultrasound signals was excited and received by a pulser/receiver (5800PR, Olympus-Panametrics NDT). Ultrasound waves were transmitted and received by a slightly concaved transducer using a piezoelectric polymer film. It had a central frequency of 30 MHz, a focal length of 20 mm, and an aperture diameter of 6.0 mm. The received ultrasound signals were digitized by a digital oscilloscope (DPO7140, Tektronix) and analyzed using fast Fourier transform (FFT) by a computer.

The measured specimen was obtained by slicing the HIFU-exposed specimen as thickness of 3-mm. The specimen was set on a stainless steel plate and covered by a polystyrene plate to receive the reflected waves stably.

The travelling time of ultrasound was obtained using linear fitting to the phase spectrum from 10 to 15 MHz. The sound speed of a specimen, c_{specimen}, was obtained as

$$c_{specimen} = c_{saline}\left(1 - \frac{t_3 - t_1}{t_3 - t_2}\right) \quad (1)$$

where, c_{saline} is the sound speed of saline solution [6], $t_{1\text{-}3}$ is the travelling time of the ultrasound

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waves as shown in **Fig. 2**. The polystyrene plate should not have any influence on the measured sound speed of the specimen because it is compensated in eq. (1).

A pair of thermally denatured and non-denatured specimen was prepared from a HIFU-exposed specimen. Five pairs of the specimen were obtained from the five HIFU-exposed specimens. Sound speed measurement was repeated five times for each specimen to validate the measurement reproducibility. The mean and standard deviation of sound speed was calculated for all of measured results.

3. Results and Discussion

Figure 3 shows mean and standard deviations of the measured sound speed for five specimens. The mean sound speed of thermally denatured and non-denatured regions was (1575.6 ± 11.3) and (1576.9 ± 14.7) [m/s], respectively. These values are approximately equal considering the standard deviation.

This result is consistent with Techavipoo's report [1] in that the sound speed of biological tissue did not changed after thermal denaturation when measured at 37°C.

On the other hand, the acoustic impedance was significantly (2.5%) decreased after thermal denaturation when measured at room temperature [3]. Because the acoustic impedance Z [$kg{\cdot}m^{-2}{\cdot}s^{-1}$] is the product of the density ρ [$kg{\cdot}m^{-3}$] and sound speed v [$m{\cdot}s^{-1}$], the measured results of the sound speed and acoustic impedance suggest that the density of the specimen was decreased after thermal denaturation.

The sound speed and acoustic impedance were measured at different temperatures although the temperature dependency of the sound speed in chicken breast muscle is not known. Further study is required to compare the sound speed and acoustic impedance at the same temperature.

4. Conclusion

In this study, we measured the sound speed of thermally denatured and non-denatured chicken breast muscle in saline solution at 36°C. These values were approximately equal considering the standard deviation.

Acknowledgment
The presented work is partly supported by Tohoku University Global COE Program "Global Nano-Biomedical Engineering Education and Research Network Centre", MEXT, Japan.

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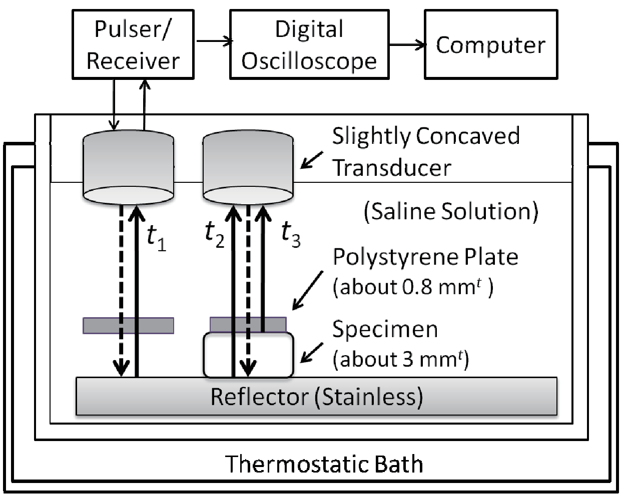

Fig. 2. Schematic diagram of sound speed measurement.

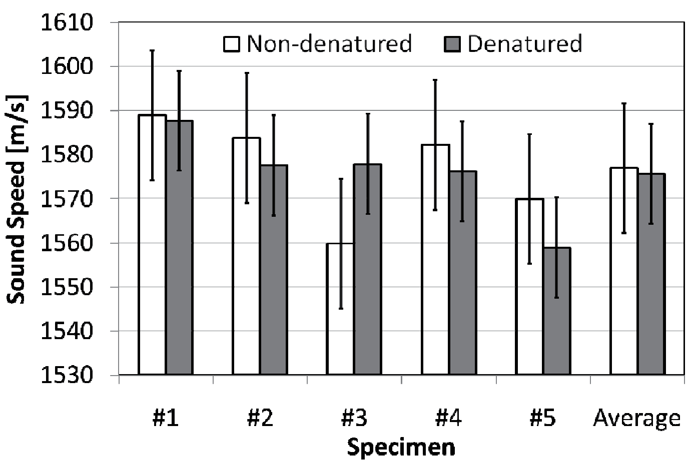

Fig. 3. Results of sound speed for five specimens.