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Acoustic Impedance Evaluation of Thermally-induced Lesion in Biological Tissue using Ultrasonic Microscopy
超音波顕微鏡を用いた加熱凝固組織の音響インピーダンス評価

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1. Introduction

High intensity focused ultrasound (HIFU) is one of noninvasive therapeutic methods. The method introduces high temperature to coagulate the target tissue. Magnetic Resonance Imaging (MRI) is used for monitoring the treatment and the therapeutic effect. It can measure the temperature of the target tissue, but an extremely high magnetic field is needed to satisfy both spatial and time resolution simultaneously. In contrast, ultrasonic echography is capable of real-time monitoring even with a conventional equipment. Furthermore, the potential errors due to diffraction can be automatically corrected if ultrasound is used for both treatment and monitoring. Monitoring with ultrasonic echography is therefore expected to become useful for HIFU.

It is known that the sound speed and attenuation of tissues change due to diseases [1, 2] and depend on their temperature [3, 4]. However, the influence of thermal coagulation on the acoustic impedance of tissues is not well known studied although the spatial change in acoustic impedance is the primary source of ultrasound echoes. In this study, we compare the acoustic impedance between non-coagulated and thermally coagulated chicken breast muscle using an ultrasonic microscope.

2. Experiments

The acoustic impedance of tissues was measured with an ultrasonic microscope (HONDA ELECTRONICS, HUM-1000) at room temperature. The focused transducer was driven with a nanosecond pulse to generate an 80 MHz ultrasonic pulse, and the echo was received by the transducer. It produced acoustic impedance maps of the sample specimen in the region of 4.8 × 4.8 mm^2 containing 150 × 150 points.

The acoustic impedance was calibrated using polystyrene and silicone pieces whose acoustic properties were known [5]. A chicken breast muscle was used as the specimen.

The acoustic impedance of non-coagulated and coagulated specimens were compared. The non-coagulated specimen was set on a polystyrene dish and measured at room temperature. After that, the specimen was heated in order to induce coagulation using a thermal bath at 70°C for 2-minutes. The acoustic impedance of the coagulated specimen was measured as well as that of the non-coagulated specimen.

The acoustic impedance of a tissue coagulated with HIFU tissue was compared with that of a non-coagulated tissue. **Figure 1** shows a cross-section of the HIFU-exposed chicken breast muscle. The specimen contains HIFU-coagulated and non-coagulated tissues. The mean and standard deviation of the acoustic impedance were calculated from that of the 2-mm^2 region of interest containing about 2000 pixels.

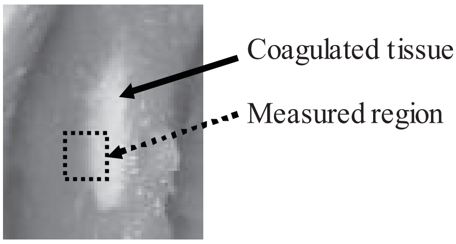

Fig. 1. Cross-section of HIFU exposed chicken breast muscle.

3. Results and Discussion

Figure 2 shows an acoustic impedance map of the non-coagulated specimen. A dark part on the lower left shows the silicone for calibration. The mean acoustic impedance of the non-coagulated and the thermally coagulated specimen was 1.75 ± 0.02× 10^6 $kg{\cdot}m^{-2}{\cdot}s^{-1}$ and 1.66 ± 0.01 × 10^6 $kg{\cdot}m^{-2}{\cdot}s^{-1}$, respectively. These values are consistent with the acoustic impedance, 1.70 × 10^6 $kg{\cdot}m^{-2}{\cdot}s^{-1}$, calculated from the reported density and stiffness (Choi *et al.*[6]).

Figure 3 shows an acoustic impedance map of the HIFU-exposed specimen. In this map, the left half shows the non-coagulated tissue and the right half shows the HIFU-coagulated tissue. The coagulated tissue has lower acoustic impedance than the non-coagulated tissue.

These results were listed on **Table I**. Both tissues show 5% decrease in acoustic impedance after coagulation. Thus, it is natural to think that the decrease in acoustic impedance occurred due to thermal coagulation.

Techavipoo *et al.*[3] measured the relationship of

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between the sound speed and thermal history of fresh canine liver. The sound speed of the specimen showed no significant change at 37°C between before and after coagulation. Choi *et al.*[4] measured a similar relationship for egg white. The sound speed decreased after coagulation because protein was denatured due to thermal exposure.

The acoustic impedance Z [$kg \cdot m^{-2} \cdot s^{-1}$] can be described by

$$Z = \rho \times v = \rho \times \sqrt{\frac{c}{\rho}}, \qquad (1)$$

where density ρ [$kg \cdot m^{-3}$], sound speed v [$m \cdot s^{-1}$] and elastic stiffness c [$kg \cdot m^{-1} \cdot s^{-2}$]. If the sound speed did not change after the coagulation as the reported by Techavipoo *et al.*, the decrease in acoustic impedance we observed would have been caused by the decrease in density. In this case, the acoustic stiffness should have decreased in the same ratio as the density. In another pint of view, if the sound speed decreased as reported by Choi *et al.*, the decrease we observed would have been caused by the decrease in sound speed. However, the decrease in acoustic impedance we observed (5%) was not quantitatively consistence with the decrease in sound speed (0.16% at 50°C) of the report. Therefore the decrease we observed would have been caused by the changes in both density and sound speed.

4. Conclusion

In this study, we compared the acoustic impedance between non-coagulated and thermal coagulated chicken breast muscles using an ultrasonic microscope. It was observed that the acoustic impedance decreased after thermal coagulation. It would have been caused by the changes in both density and sound speed due to thermal coagulation.

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Table I. Measured acoustic impedance of the specimens.

Heating method	Non-coagulated $\times 10^6$ [$kg \cdot m^{-2} \cdot s^{-1}$]	Coagulated $\times 10^6$ [$kg \cdot m^{-2} \cdot s^{-1}$]	Difference $\times 10^6$ [$kg \cdot m^{-2} \cdot s^{-1}$]	Relative difference [%]
Thermal bath	1.75±0.02	1.66±0.01	-0.09	-5.0
HIFU	1.74±0.03	1.65±0.03	-0.09	-4.8

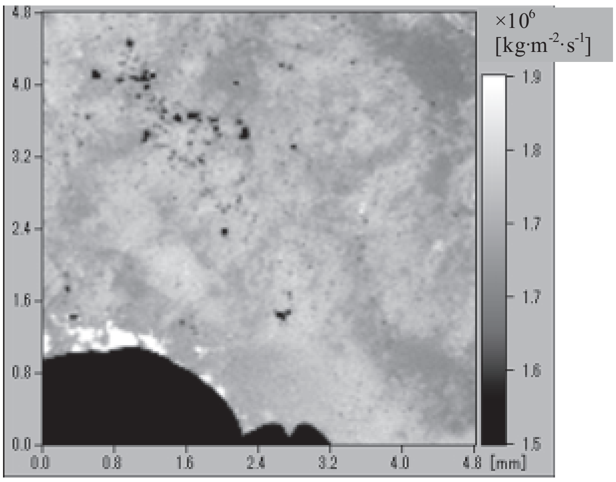

Fig. 2. Acoustic impedance map of the non-coagulated specimen.

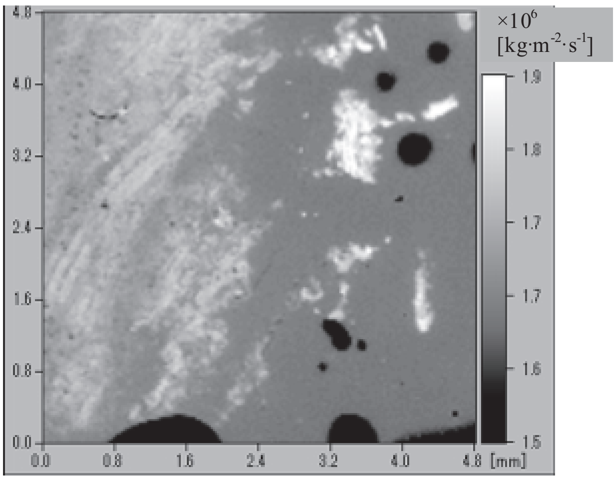

Fig. 3. Acoustic impedance map of the HIFU-exposed specimen.