A Basic Study on Effect of Shielding Objects on Focused Ultrasound Treatment by Acoustic Radiation Force Imaging

Erika Numahata[1‡], Shin Yoshizawa[1,2,3], Shin-ichiro Umemura[1,3], Takuro Ishii[4], Yoshifumi Saijo[1] ([1]Grad. School of Biomed. Eng., Tohoku Univ.; [2]Grad. School of Eng., Tohoku Univ.; [3]SONIRE Therapeutics; [4]Frontier Research Institute for Interdisciplinary Sciences)

1. Introduction

HIFU is a minimally invasive treatment in which ultrasound waves are irradiated from outside the body and focused inside the body to selectively heat and coagulate tissue. The problem with this treatment is that the treated region cannot be seen by the naked eye. Therefore, it is necessary to estimate the treatment region in advance using ultrasound images to improve the safety and efficacy of the treatment.

The previous study[1)] showed that acoustic radiation force (ARF) imaging is effective as a predictor for the heat which should be generated in the HIFU focal region. This estimation method is based on the approximation that the distribution of HIFU heat source is proportional to the ARF induced by a very short HIFU exposure.

In actual clinical practice, when a liver cancer is targeted, the HIFU transducer can be partially blocked by the ribs, which may result in inadequate treatment to the targeted region. Therefore, in this study, we estimated the heating distribution in the presence of shields such as ribs, and investigated a correction method for such cases.

2. Materials and Methods

2.1. HIFU heat source estimation by ARF

When tissue is exposed to ultrasound waves, ARF is generated. ARF F is expressed as,

$$|F| = \frac{2\alpha I}{c} \tag{1}$$

where α is the acoustic attenuation coefficient, I is the acoustic intensity, and c is the longitudinal sound velocity in biological tissue.

The heat quantity Q generated by HIFU exposure is expressed as,

$$Q = 2\alpha_a I \tag{2}$$

where α_a is the acoustic absorption coefficient. Assuming that most of the attenuation is due to absorption, the right-hand sides of equations (1) and (2) are proportional. In addition, F can be approximated to be proportional to the tissue displacement u. Therefore, the heat generation and displacement are also approximately proportional, and the heat generation distribution can be estimated from the displacement distribution.

In the estimation method used in this study, HIFU is first applied for a short period of time, and the displacement caused by the ARF is detected by ultrasonic echoes. The displacement distribution obtained from the ultrasound echoes is used as the estimated coagulation area. Next, HIFU at the same intensity is continuously irradiated for tens of seconds to generate thermal coagulation. The process of displacement detection is called the estimation mode, and the process of generating coagulation and actually performing treatment is called the coagulation mode in this study.

2.2. Experimental setup and Sequence

The experimental setup is shown in **Fig. 1**. A chicken breast tissue was vacuum compressed in a plastic bag and placed in a water tank filled with degassed and deionized water at room temperature. The tissue was placed in room-temperature saline solution and degassed for 3 hours before enclosed in the bag. A 256-channel HIFU transducer was placed in the tank and driven at 1 MHz by a driving system (Microsonic). A sector probe was placed in the central hole of the HIFU transducer and connected to an ultrasound imaging system (Verasonics) to acquire RF data. Two 12 mm diameter rods were placed on one side of the HIFU transducer to simulate ribs. Before the HIFU exposure experiment, the acoustic pressure at the focal point was measured in two patterns, one without the rods and the other with the rods. The pressure with the rods was about 10% lower than that without the rods.

The ultrasound exposure sequence is shown in **Fig. 2**. In the estimation mode, RF data were acquired by transmitting a single plane wave before and after HIFU exposure, with an interval of 0.8 ms after HIFU exposure to reduce interference of HIFU with the ultrasound imaging. A two-dimensional combined autocorrelation method[2)] was applied between frames before and after the HIFU push-

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erika.numahata.p3@dc.tohoku.ac.jp

beam exposure to calculate axial displacement. In the coagulation mode, coagulation was generated with HIFU with a duration of 20 s, whose total acoustic power (TAP) of 40 W was the same as the push-beam.

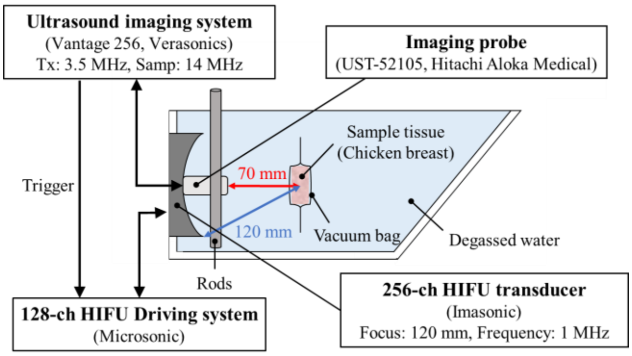

Fig. 1 Schematic of experimental setup.

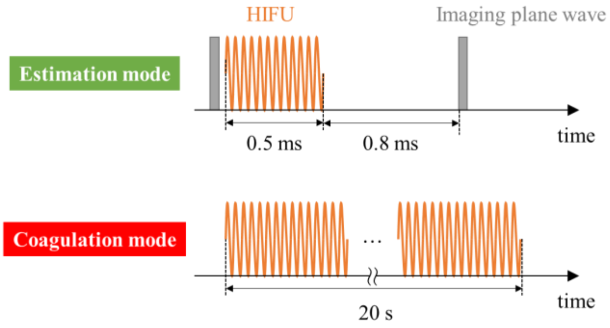

Fig. 2 Ultrasound exposure sequence.

3. Results and Discussion

Fig. 3 shows the results of the estimation mode without and with rods. **Fig. 3**(a) shows the result of the estimation mode without rods, and **Fig. 3**(b) shows the result of the estimation mode with rods inserted and the amplifier voltage adjusted so that the intensity at the focal point is the same value as without rods. Comparing (a) and (b), there was no significant difference in the magnitude of displacement and the area of displacement despite the different amplifier voltage values.

Fig. 4 shows the set of results for the estimation and coagulation modes without and with rods. **Figs. 4**(a) and **4**(b) show the results of both modes without rods, while **Figs. 4**(c) and **4**(d) show the results of both modes when rods were inserted and at different locations than in **Figs. 4**(a) and **4**(b), using the voltage values used in **Fig. 3**(b). Comparing the results of the estimation mode, there was no significant difference in the area of displacement and the magnitude of displacement. Comparing the results of the coagulation mode, the coagulated area was almost the same. In both cases, coagulation was generated at a depth of 65 to 75 mm, while in the estimated mode, a displacement area was observed at a depth of 60 to 72 mm. The shift in the displacement peak of the estimated mode may be attributed to the overlap of the HIFU beams on the axial axis as the shear wave propagates$^{3)}$ and also to the approximation assuming that the displacement is proportional to the ARF.

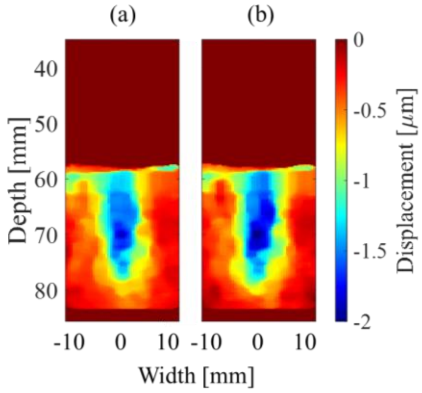

Fig. 3 Displacement distributions in chicken breast induced by HIFU at a TAP of 40 W with a duration of 0.5 ms (a) without rods and (b) with rods.

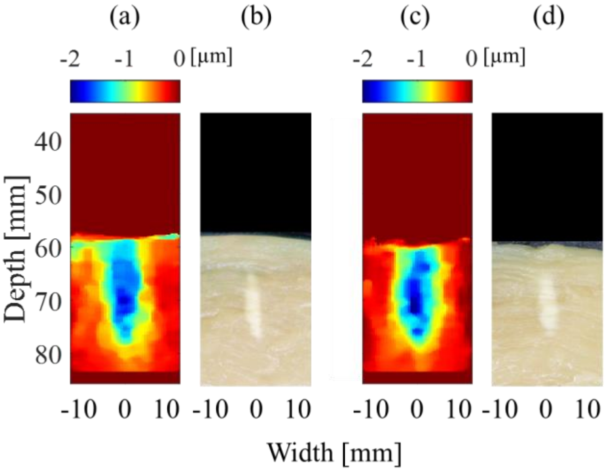

Fig. 4 Comparison between (a) displacement distributions without rods, (b) coagulated tissue without rods, (c) displacement distributions with rods, (b) coagulated tissue with rods.

4. Conclusion

The results suggest that even in the presence of partial acoustic shielding, it may be possible to generate coagulation almost the same as that without the shielding if the HIFU output intensity is adjusted so that the estimation mode displacements should be equal.

References

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