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Effect of HIFU reverberation component on estimation of HIFU heating distribution by acoustic radiation force imaging

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1. Introduction

High-intensity focused ultrasound (HIFU) is a minimally invasive method for a cancer treatment. In this treatment, ultrasound waves are delivered from outside the body onto the treated tissue to coagulate and necrosis it. One of the methods for visualizing the focal region of HIFU is ultrasound imaging of tissue displacement caused by an acoustic radiation force (ARF) by HIFU. In the previous studies, the ARF imaging using HIFU was applied to the estimation of heat source in HIFU treatment by utilizing the relationship that the displacement induced by ARF is proportional to the heat generation due to ultrasound absorption[1,2]. In this method, it is important to acquire the displacement distribution immediately after HIFU sonication to reduce the effect of shear wave propagation on the measurement for highly accurate heat source estimation. However, immediately after HIFU sonication, interference of HIFU with imaging ultrasound degenerates the measurement accuracy of tissue displacement. Therefore, in this study, we aimed to improve the measurement accuracy of tissue displacement by ARF immediately after HIFU sonication by reducing the interfered waves by HIFU.

2. Materials and Method

2.1 Experimental setup

Fig. 1 shows the experimental setup used in this study. A 256-channel 2D array transducer with a focal length of 120 mm was used to generate HIFU at a frequency of 1 MHz, and an imaging sector probe (Hitachi Aloka Medical; UST-52105) was placed in the central hole of the HIFU transducer. Experiments were performed in degassed water (dissolved oxygen saturation 20-25%). The imaging probe was connected to an ultrasound imaging system (Verasonics; Vantage256), which transmitted plane waves at a center frequency of 3.5 MHz and acquired RF data at a sampling frequency of 14 MHz. Gizzard was used as the biological sample and was degassed for approximately 3 hours while immersed in 0.9% saline solution.

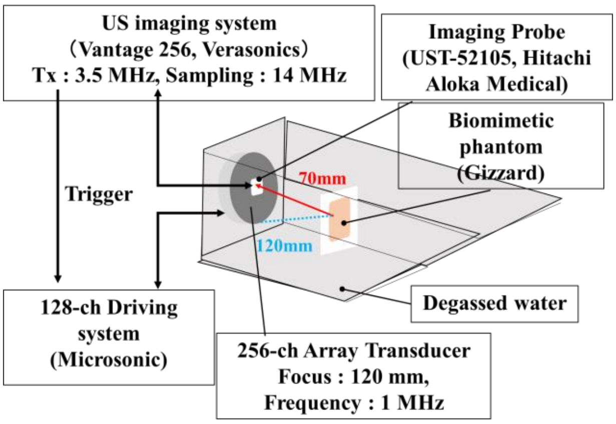

Fig. 1 Experimental setup.

2.2 HIFU sequence

Degassed gizzards were exposed to HIFU burst waves at a frequency of 1 MHz for 0.2 ms. Before and after HIFU sonication, the ultrasound imaging probe placed at the center of the HIFU transducer were used to transmit plane wave at 3.5 MHz and acquire RF data. The focal point of HIFU was at 70 mm depth from the imaging probe. Imaging was performed before and 0.2 ms after HIFU. The HIFU total acoustic power (TAP) was set to 80 W and the imaging acoustic pressure was set to 0.15 MPa.

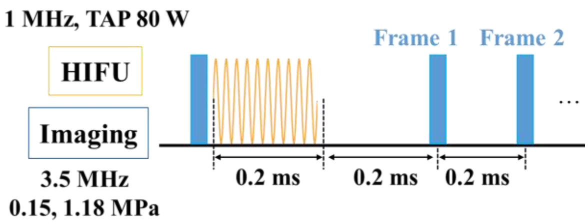

Fig. 2 HIFU exposure sequence.

2.3 Measurement of tissue displacement induced by ARF using HIFU

Immediately after the HIFU sonication, the imaging pulse waves are negatively affected by the interference of HIFU burst waves. Since the HIFU burst wave has a narrow frequency band, two notch filters were applied to RF signals acquired by the imaging probe to reduce signals with 1 MHz (fundamental frequency of HIFU) and 2 MHz (second harmonic frequency of HIFU), respectively. A 6th order notch filter was used and the 3 dB bandwidth of the filter was set to 0.05 for 1 MHz and 0.03 for 2 MHz. The filtered RF data were beamformed based on the delay-and-sum approach. Then, the tissue displacement induced by ARF was measured from the phase of complex cross-correlation of beamformed data between frames before and after the HIFU sonication.

3. Result and Discussion

Fig. 3 shows (a) B-mode image of gizzard, (b) numerically simulated HIFU intensity (Fig. 3(b)), and (c, d) measured tissue displacements. Figs. 3(c) and 3(d) show results without and with applying the notch filter, respectively. In Fig. 3(c), the estimated tissue displacements shows different distribution compared to the simulated HIFU intensity in Fig. 3(b). From the frequency spectrum of RF data in Fig. 4, it is considered that this is due to the 1 MHz and 2 MHz components of the HIFU reverberation. By reducing 1 MHz and 2 MHz components by notch filters, a similar pattern with simulated HIFU intensity (Fig. 3(b)) was observed as shown in Fig. 3(d). This suggests that even immediately after HIFU sonication, which is largely affected by HIFU reverberation, the measurement of displacement distribution is possible by applying appropriate filtering, that contributes to the accurate estimation of heat source distribution.

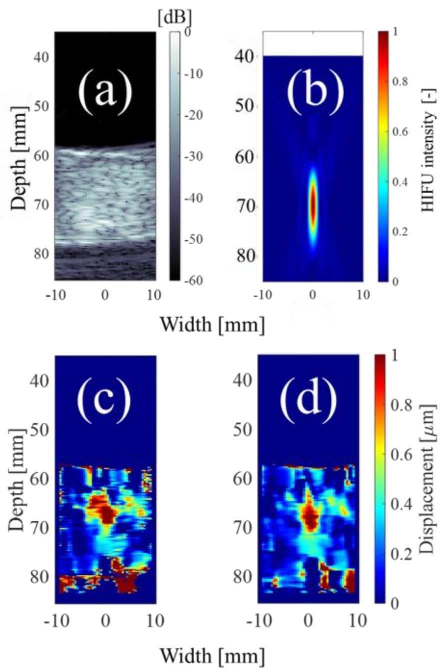

Fig. 3 (a) B-mode image of gizzard.
(b) Numerically simulated HIFU intensity.
(c) Estimated tissue displacement without applying notch filter.
(d) Estimated tissue displacement after applying notch filter to RF data.

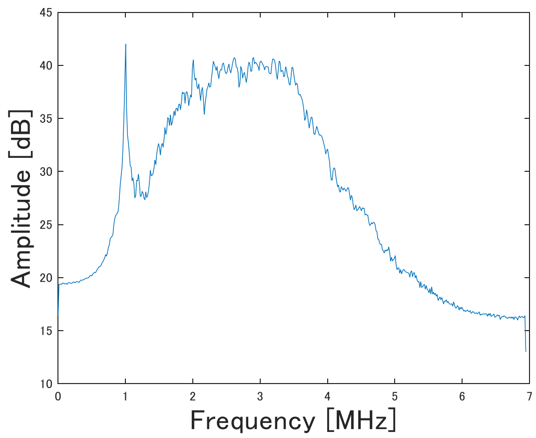

Fig. 4 Fourier spectrum of RF data before applying notch filter.

4. Conclusion

This study shows that the applying a notch filter is effective to measure the tissue displacement immediately after the HIFU sonication. The measurement of tissue displacement induced by ARF before the shear wave propagation is important to improve the accuracy of heat source distribution estimation. Therefore, the removal of HIFU reverberation which enables the measurement of tissue displacements immediately after the HIFU irradiation will contribute to the accurate estimation of HIFU heat source before the HIFU treatment.

References

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