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Ultrasound imaging method of cavitation bubbles by superimposing HIFU pulse on imaging pulse

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1. Introduction

High-intensity focused ultrasound (HIFU) thermal treatment using cavitation bubbles has two advantages: visualization of the treatment area by ultrasound imaging of bubbles and improvement of the ultrasonic heating. In this technique, it is important to set the HIFU intensity appropriately for cavitation generation before the treatment. For example, the HIFU intensity can be determined by the sonication of HIFU to the target tissue while varying the intensity of the HIFU pulses and detecting the generated bubbles. Currently, the Pulse-Inversion (PI) technique is widely used to detect cavitation bubbles in ultrasound imaging, which detects harmonic components in the reflected wave from the bubbles. However, the sensitivity of this technique for detecting bubbles is not always sufficient. Therefore, we propose a new bubble detection technique in which imaging and HIFU pulses are superimposed on each other. The superimposed HIFU pulses increase the scattering cross-sectional area of bubbles to ease the detection of bubbles. We compare and discuss the proposed technique with the conventional PI technique.

2. Materials and Methods

a. Experimental Setup

The experimental setup for this study is shown in Fig. 1. HIFU exposure was performed in a water tank filled with purified water degassed to less than 20% oxygen saturation. A 128-channel array transducer with aperture of 148 mm, radius of curvature of 120 mm, and center frequency of 1 MHz was used for HIFU exposure. For ultrasound imaging, a 128-channel sector probe was inserted into the central hole of the HIFU transducer. Degassed chicken breast tissue was used as the target tissue.

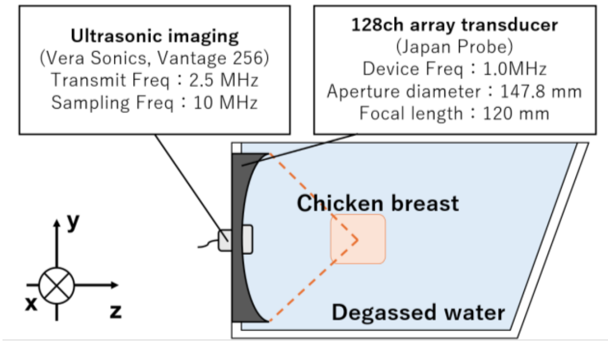

Fig. 1 Experiment setup

b. Ultrasound Exposure

The ultrasound exposure sequence is shown in Fig. 2. To generate cavitation bubbles, 100 μs of high-intensity HIFU pulses (Trigger Pulses) at a center frequency of 1 MHz and a focal pressure of 118 MPapp were sonicated. After 4.9 ms, three ultrasound imaging pulses were transmitted at 250 μs intervals, with the initial phase of the first pulse set to 0° and the second pulse shifted 180° from the initial phase. The third ultrasound imaging pulse was delivered with an initial phase of 0° and was superimposed with low-intensity HIFU pulses (Excitation Pulses) at a center frequency of 1 MHz and a focal pressure of 16.5 MPapp, and with a duration of 4 μs. To investigate the relationship between the acoustic field of the Excitation Pulses and bubble detection performance, the focal point of the Trigger Pulses was shifted by up to 8 mm at 2 mm intervals from the focal point of the Excitation Pulses as shown in Fig. 3, and the effect on the bubble detection sensitivity was investigated. The focal point of the Trigger Pulses was offset 4 mm from the geometric focal point in the propagation direction to account for the effect of shock

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scattering[1], in which a cavitation bubble cloud is formed by reflected waves from individual bubbles.

c. Signal Processing

A high-pass filter with a cutoff frequency of 2.5 MHz was applied to all three received signals to reduce HIFU reverberation components. The first and second received signals were added together to produce a PI image, which is a conventional technique. The difference between the first and third received signals was used to produce the image of the proposed technique.

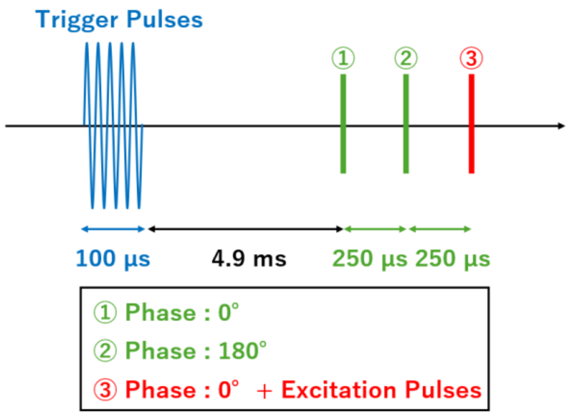

Fig. 2 HIFU exposure sequence

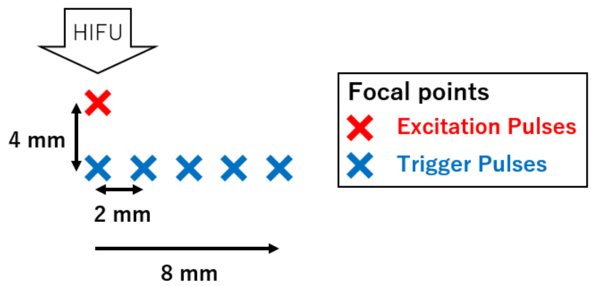

Fig. 3 Focal point

3. Results and Discussion

The single-pulse (1P) image, the PI image, and the image obtained by the proposed technique are shown in Fig. 4, where the Trigger Pulses and the Excitation Pulses are focused in the same direction. The contrast ratio of the bubble region to the tissue region was calculated to be 12.5 dB for the PI method and 36.6 dB for the proposed method, confirming that the proposed technique improves the sensitivity of the bubble detection. Fig. 5 shows the change in the contrast ratio between the bubble region and the tissue region when the focus position of the trigger pulses is shifted by 0 - 10 mm. The contrast ratio decreased as the bubbles moved away from the focus of the Excitation Pulses. This result indicates that the proposed technique can detect bubbles with high sensitivity depending on the acoustic pressure of the Excitation Pulse. This indicates that HIFU sonication at the same level of intensity as Excitation Pulse to the induced cavitation may cause the volumetric oscillation of the bubbles and provide a heating enhancement effect in a thermal HIFU treatment using cavitation.

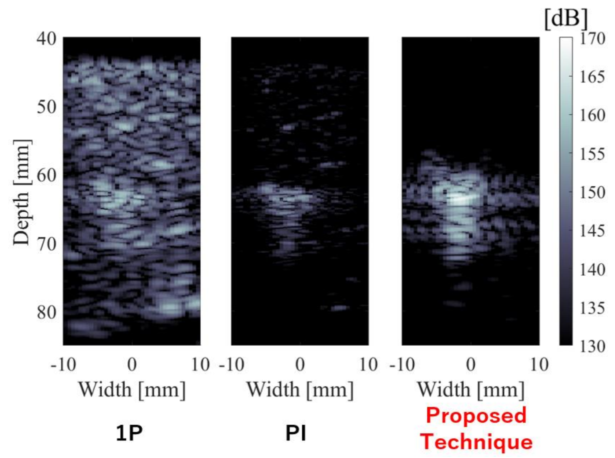

Fig. 4 B-mode Image

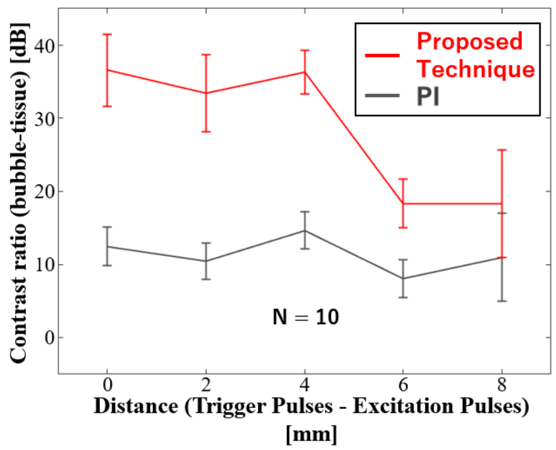

Fig. 5 Contrast ratio change

4. Conclusion

The cavitation bubble detection technique proposed in this study shows better imaging sensitivity than the conventional PI technique.

References

1) A. D. Maxwell et al.: J Acoust. Soc. Am., 130, (2011).