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Study of Cavitation Behavior during High-Intensity Focused Ultrasound Exposure by Using Flash Imaging
強力集束超音波照射中のキャビテーション気泡挙動のフラッシュイメージングによる観察

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1. Introduction

High-intensity focused ultrasound (HIFU) treatment is a noninvasive method of treatment in which ultrasound is focused to a target tissue such as cancer to be thermally coagulated. Acoustic cavitation bubbles are known to accelerate the therapeutic effect of HIFU treatment. They can typically be generated by a high-intensity short pulse ("trigger pulse") and accelerate the effect of an immediately following HIFU burst at a relatively low intensity ("heating waves") in a "triggered HIFU sequence"[1)]. In our previous study, it was demonstrated that such bubbles can be detected by high-speed ultrasonic imaging with unfocused transmission in spite of their short lives. It has also been known that a pulse inversion[2)] (PI) method can selectively detect the nonlinear echoes from bubbles in the resonance size.

In this study, the behavior of cavitation bubbles during the exposure of "heating waves" in a "triggered HIFU sequence" is investigated by high-speed ultrasonic imaging as well as high-speed photography. The objective is to check the life of cavitation bubbles that can enhance the heating effect of the treatment.

2. Materials and Methods

2.1 Graphite gel phantom

An acrylamide gel phantom was prepared for simultaneous high-speed photography observation. It contained a 0.5% graphite powder layer with a thickness of 0.75 mm as a linear ultrasonic scatterer to characterize the scattering by cavitation bubbles.

2.2 HIFU exposure

HIFU was generated by a 256-element array transducer (Imasonic) at 1.2 MHz with both outer diameter and geometrical focal length of 120 mm.

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2.3 Ultrasound imaging

Cavitation bubbles were observed using a sector array probe (UST-52105, Hitachi Aloka Medical) with a center frequency of 3.0 MHz connected to a programmable ultrasound imaging system (V1, Verasonics). We applied plane wave transmission followed by parallel beamforming[3)] to achieve a frame rate of 5000 fps. Plane imaging pulses with positive and negative initial polarities were transmitted, with which RF data for a PI method were acquired.

2.4 Experimental setup and sequence

Fig. 1 shows a schematic of the experimental setup. A graphite gel phantom was submerged in degassed water in a tank. The graphite layer was set parallel to HIFU transmission so that it contained the focal point.

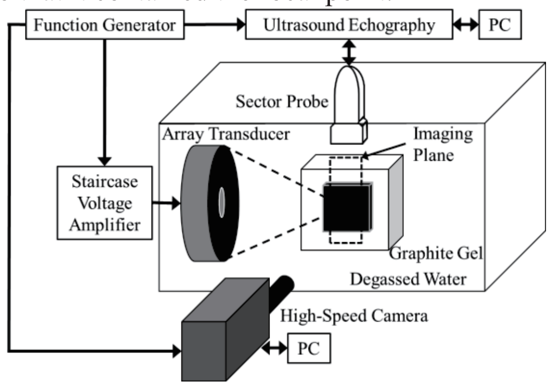

Fig. 1 Schematic of experimental setup

The sequence of HIFU exposure and RF data acquisition is shown in **Fig. 2**. The phantom was exposed to a trigger pulse at a maximum intensity of 60 kW/cm^2 for 100 µs for generating cavitation bubbles. Immediately after that, it was exposed to heating waves at a maximum intensity of 1 kW/ cm^2 for 0 to 500 ms for sustaining the bubbles. 700 µs after the heating waves were ceased, plane wave imaging pulses with positive and negative initial polarities were transmitted from the sector probe.

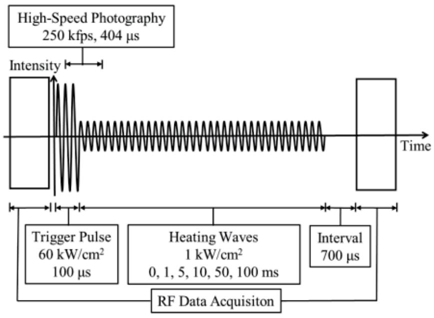

Fig. 2 Sequence of HIFU exposure and RF data acquisition

3. Result and Discussion

Fig. 3 shows the B-mode images, in which the HIFU propagated from left to right. Echoes at relatively high amplitudes are observed in the HIFU focal region, which was consistent with high-speed optical images.

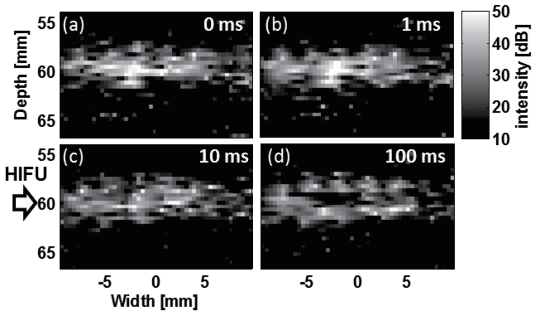

Fig. 3 B-mode images at 1.61 MHz
Duration of heating waves
(a)0 ms (b)1 ms (c)10 ms (d)100 ms

The contrast ratio of mean brightness between the cavitation bubbles and the reference graphite powders was calculated and shown in **Fig. 4**. Immediately after the trigger pulse, the contrast ratio of PI image was much higher than that of linear image without PI. As the duration of heating waves increased, it dropped much faster than the linear echoes.

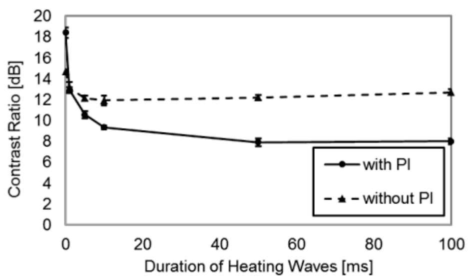

Fig. 4 Contrast ratio of mean brightness between cavitation bubbles and reference graphite powder

Fig. 5 shows the power spectra of the RF data obtained by imaging transmission pulses at 1.61 and 3.21 MHz received after heating wave duration of 0 and 100 ms, respectively. Higher harmonic components significantly decreased after the heating wave duration of 100 ms. It is less significant at a imaging transmission frequency of 1.61 MHz, resulting in that the spectra of 0 to 6 MHz only slightly depend on the imaging transmission frequency.

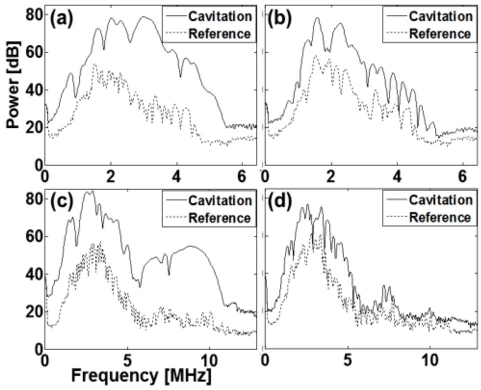

Fig. 5 Power spectra of RF data
(a)1.61 MHz, 0 ms (b)1.61 MHz, 100 ms
(c)3.21 MHz, 0 ms (d)3.21 MHz, 100 ms

The decrease of nonlinear echoes seen in Fig.4 may imply that the size of bubbles have shifted away from the resonance during the heating wave exposure. The results shown in Fig. 3 also suggest that bubbles drifted away from the HIFU focus after the duration of 100 ms.

4. Conclusion

By using a high-speed ultrasonic imaging method, the behavior of cavitation bubbles during HIFU exposure were investigated. The results suggest that the life of bubbles, which may be limited for enhancing HIFU treatment, can be monitored by the method. This study is helpful for optimizing the triggered HIFU sequence.

Acknowledgment

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