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Simultaneous High-Speed Optical and Acoustic Observation of Cavitation Bubbles Generated in Biological Tissue

生体組織中に発生させたキャビテーション気泡群の光学的及び音響的高速同時観察

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1. Introduction

High-intensity focused ultrasound (HIFU) is a type of noninvasive cancer treatment, in which ultrasound is generated outside the body and focused onto a target tissue to be thermally coagulated. Acoustic cavitation bubbles can accelerate the therapeutic effect of HIFU treatment. In our previous study, it was demonstrated that the "triggered HIFU sequence" consisting of a high-intensity short pulse ("trigger pulse") and a following relatively low intensity HIFU burst ("heating burst") could generate cavitation bubbles and sustain their bulk vibration[1)]. Cavitation has a potential to enhance HIFU treatment but its behavior in biological tissue remains unexplained. In this study, we observed its behavior in a biological phantom by high-speed photography and high-speed ultrasonic imaging simultaneously on the objective to estimate the behavior of cavitation bubbles in biological tissue.

2. Materials and Methods

2.1. Biological phantom

In this study we prepared an acrylamide gel containing a piece of chicken breast tissue in the size of 20×20×10 mm. It had a whole shape of a truncated square pyramid as shown in **Fig. 1**.

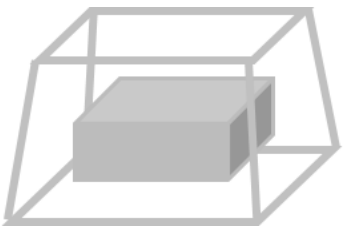

Fig. 1　Schematic of biological phantom

2.2. Cavitation imaging method

A sector array probe (UST-52105, Hitachi Aloka Medical) with a center frequency of 3.0 MHz was connected to a programmable ultrasound imaging system (Vantage 256, Verasonics) for acoustic imaging. Plane wave transmission was applied to achieve a high frame rate in the order of 1 kfps. In addition, a pulse inversion (PI) method[2)] was applied to detect the nonlinear echoes from bubbles. For optical imaging, a high-speed video camera (Phantom V1211, Vision Research) with a frame rate of 20kfps and a pulse laser diode (CAVILUX Smart, CAVITOR) with a luminescence pulse length of 50 ns were used.

2.3. Experimental setup and sequence

A schematic of the experimental setup is shown in **Fig. 2**. All experiments were conducted in a water tank filled with degassed water. A HIFU array transducer (Imasonic) embedded in the water tank had 256 elements and both outer diameter and geometrical focal length of 120 mm. The biological phantom was submerged in the water tank and one of the boundary surfaces between the gel and tissue was positioned so that it contained the axis of HIFU including the focal point. The sequence of HIFU exposure and RF data acquisition is shown in **Fig. 3**. The target phantom was exposed to a trigger pulse with a maximum intensity of 60 kW/cm^2 for 100 μs for generating cavitation bubbles. Just after that, it was exposed to a heating burst with a maximum intensity of 1 kW/cm^2 for sustaining the bubbles. Ultrasonic plane wave imaging pulse was transmitted from sector probe 700 μs after the end of the heating burst.

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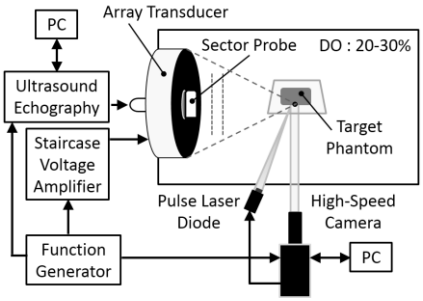

Fig. 2 Schematic of experimental setup

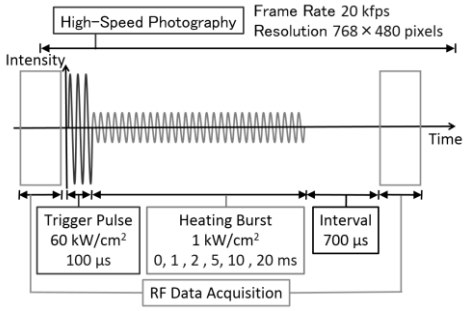

Fig. 3 HIFU sequence and RF data acquisition

3. Results and Discussions

Fig. 4 shows high-speed photography. To obtain each frame, the variance of 5 consecutive raw frames was calculated and then binarized. The cross line in each figure corresponds to the focus of HIFU propagating from the right to the left. A cavitation cloud generated during the trigger pulse irradiation, fine bubbles oscillation during the heating burst irradiation, and their disappearance just after the end of the burst were observed. As the duration of heating burst increased, the oscillating bubbles tended to vanish even during the irradiation. **Fig. 5** shows the difference of B-mode images between before and after the HIFU exposure. The cross line in each figure also corresponds to the focus of HIFU propagating from the right to the left. The dotted lines show the boundary of the tissue, which was detected from plane wave images. Relatively bright echoes indicate cavitation bubbles, showing that bubbles continued existing even after the HIFU exposure ended.

Each cavitation area detected by both imaging methods was mostly consistent, which demonstrated that both methods are useful for monitoring cavitation. However, the ultrasonic method was able to detect cavitation (Fig. 5), which the optical method was not (Fig.4 (3)). This suggests that the ultrasonic sensitivity to cavitation in biological tissue was significantly higher than the optical sensitivity, at least in the presented setup.

4. Conclusion

In this study, we analyzed the behavior of cavitation bubbles simultaneously by two methods, high-speed photography using light scattering and high-speed ultrasonic imaging with a compound PI method. Each method was able to detect cavitation bubbles generated in biological tissue phantom. The optical sensitivity to detect such cavitation bubbles was more limited than the ultrasonic sensitivity, but two simultaneous methods were proven to be useful to observe such cavitation behavior.

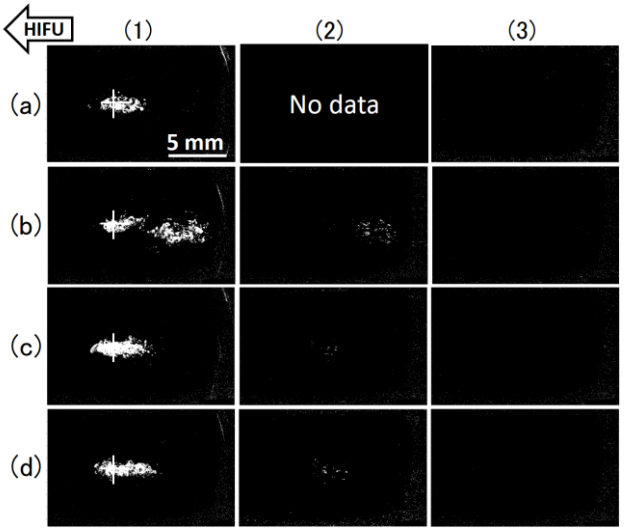

Fig. 4 High-speed photography
(Calculated variance and then binarized)
Duration of heating waves
(a) 0 ms (b) 1 ms (c) 5 ms (d) 10 ms
Each figure was taken at
(1) During trigger pulse exposure
(2) During heating waves exposure
(3) Just after HIFU exposure

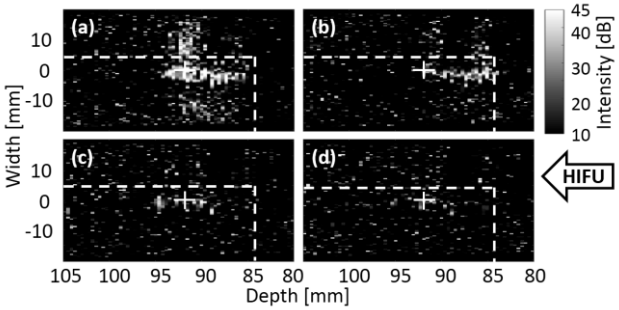

Fig. 5 Difference of B-mode image
Duration of heating waves
(a) 0 ms (b) 1 ms (c) 5 ms (d) 10 ms

References

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