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Effect of Spot Scanning Method of Ultrasonic Focus on Heating Efficiency in Cavitation-enhanced Ultrasonic Heating

気泡援用超音波加熱における焦点走査方法の加熱効率への影響

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1. Introduction

High-intensity focused ultrasound (HIFU) treatment is a noninvasive method of cancer treatment. In a HIFU treatment, ultrasound generated outside body is focused on a target tissue and the cancer tissue is coagulated through temperature rise. A HIFU treatment has a problem of long treatment time because a tumor is usually larager than the focal region of HIFU. Therefore, a method of ultrasonic heating with high efficiency is required.

Cavitation bubbles can be used to improve the heating efficiency of HIFU. Cavitation bubbles are generated by a highly negative pressure in the focal region of HIFU and can enhance ultrasonic heating[1)]. The "triggered HIFU sequence" was developped[2)] for the efficient cavitation-enhanced heating. The sequence consists of two types of ultrasound. One is a high-intensity short pulse called "trigger pulse". It generates cavitation bubbles. The other is a low- to moderate-intensity long burst called "heating burst". It oscillates cavitation bubbles to enhance the heating. The trigger HIFU sequence was combined with a method of multiple focal spot scanning[3)]. With this method, it is possible to coagulate the region between the multiple focal points by heat conduction. Therefore, the number of HIFU exposure can be decreased, which results in the treatment time reduction.

In this study, three focal scanning sequences were tested. The effect of focal scanning methods for six focal points on heating efficiency was investigated by the observation of cavitation bubbles and measurement of temperature.

2. Materials and Method

2.1 Experimental Setup

Fig. 1 shows the experimental setup. A 2D array transducer (Japan Probe) with 128 elements generates ultrasound at 1 MHz. Its diameter and focal length are 147.8 and 120 mm, respectively. A HIFU target was 1% agarose gel with a thermocouple 0.3 mm in diameter from behind it. The head of the thermocouple was set at the geometric focal point. These were placed in degassed water (dissolved oxygen saturation of 20-25%). Cavitation bubbles were backlit by a pulsed laser with a pulse duration of 20 ns and wavelength of 640 nm, and observed with a high speed camera.

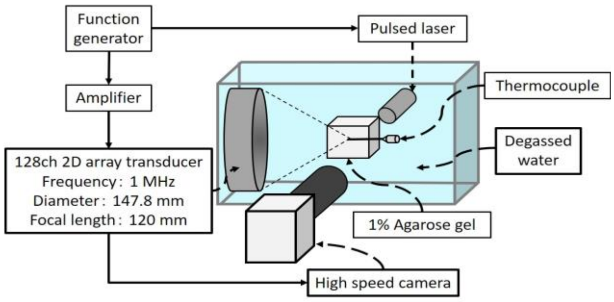


Fig. 1 Experimental setup.

2.2 HIFU exposure sequences

Fig. 2 shows the HIFU exposure sequences and **Fig. 3** shows the position of six focal points. The focal points were set at vertices of regular hexagon in a plane where the geometric focal point exists. The distance between the neighboring focal points were 3 mm. The hexagon was rotated 15 degrees in order not to overlap cavitation bubbles at each focal point in high-speed images. Trigger pulses were focused to 6 mm beyond the plane where geometric focal point exists because cavitation babbles tend to be generated backwards from its focal point[4)]. In Sequence 1, trigger pulses were exposed in the order from no.1 to 6 focal points shown in **Fig. 3**, and repeated heating bursts in the same order. In Sequence 2, trigger pulses were focused in the order of no.1, 3, 5, 2, 4, and 6, and repeated heating bursts in the same order. In Sequence 3, at first, trigger pulses were focused in the order of no.1, 3, and 5, and repeated heating bursts in the same order. Next, to no. 2, 4, and 6 focal points, HIFU was irradiated in the same way. One cycle of each sequence was 50 ms and the cycle was repeated 60 times, in total 3 s. The intensity of trigger pules was 165 kW/cm². The intensities of heating burst were 1.0 and 3.0 kW/cm².

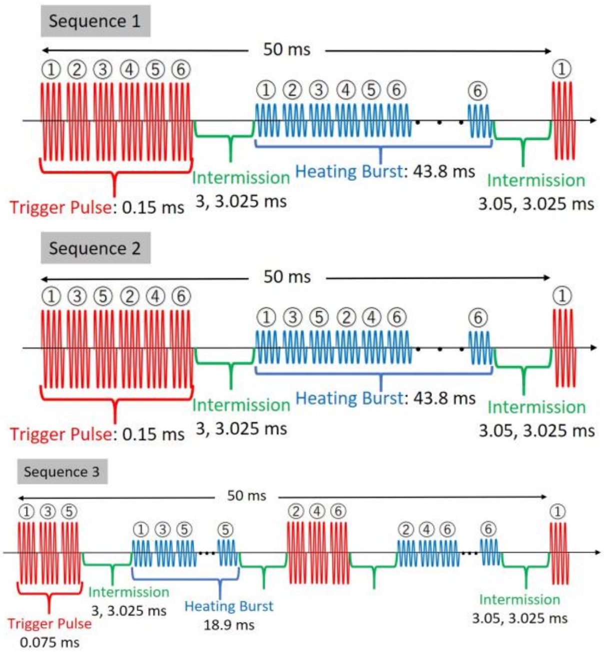


Fig. 2 HIFU exposure sequences.

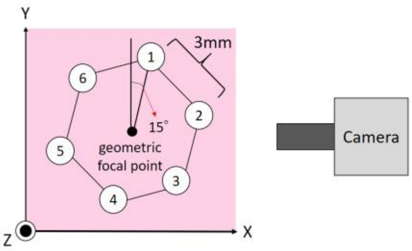


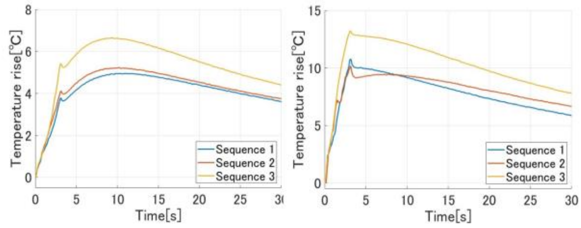
Fig. 3 Position of six focal points.

3. Result and Discussion

Fig. 4 shows results of the temperature rise with three sequences. The temperature rise was the highest with Sequence 3 and almost same with Sequence 1 and 2. The same trend was obtained at the intensities of heating burst of 1.0 and 3.0 kW/cm².

Fig. 5 shows the high-speed images of cavitation bubbles generated by HIFU exposure with each sequence at the intensity of heating burst of 3.0 kW/cm². All images were photographed during the heating burst exposure. At 1st cycle, the amount of bubbles was almost the same with all sequences. However, at 30th cycle and 60th cycle, the amount of bubbles was the largest with Sequence 3.

Considering the result of the temperature rise and the high-speed images of cavitation bubbles, the temperature rise was the highest in three sequences because of the largest amount of cavitation bubbles with Sequence 3. More cavitation bubbles might be generated because cavitation bubbles generated at the neighboring points did not interfere with the trigger pulse, and the focal intensity of the trigger pulse did not decrease.

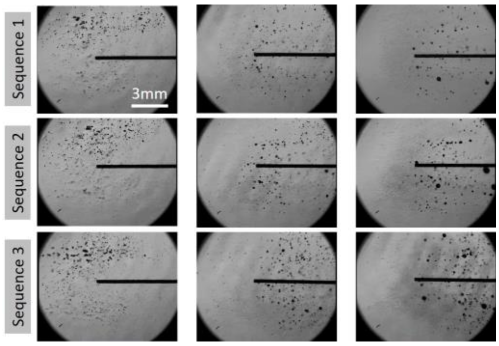


(a) (b)

Fig.4 Temperature rise

(a) Heating burst intensity: 1.0 kW/cm².

(b) Heating burst intensity: 3.0 kW/cm².



(a) (b) (c)

Fig. 5 Cavitation bubbles during heating burst exposure

(a) 1st cycle (b) 30th cycle (c) 60th cycle

4. Conclusion

In this study, HIFU was focused to with three scanning sequences for six focal spots and the temperature rise and the cavitation bubble region were compared. The results showed that HIFU exposure with Sequence 3 might contribute to generating more bubbles, and the temperature rise was the highest with it. Therefore, focal scanning methods have effects on heating efficiency in cavitation-enhanced HIFU treatment.

References

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