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Effect of Cavitation Bubbles outside Focal Region on Ultrasonic Heating in High-Intensity Focused Ultrasound Exposure by Split-Aperture Transmission

開口分割 HIFU 照射における焦点領域外キャビテーション気泡の超音波加熱への影響

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1. Introduction

High-intensity focused ultrasound (HIFU) treatment is attracting attention as a noninvasive cancer treatment. In a HIFU treatment, ultrasound generated outside a body is focused onto a target tissue for its thermal coagulation. Cavitation bubbles can be generated by a highly negative pressure in a HIFU focal region, and are known to oscillate in the acoustic field and enhance the ultrasonic heating.[1)] Therefore, it is desirable to generate cavitation bubbles only in the focal region for the efficacy and safety of the treatment. If cavitation bubbles are generated outside the treatment region, they may cause side effects such as a skin burn. It is known that bubbles migrate toward the nodes and antinodes in a standing wave field and coalesce.[2)] To reduce the risk of undesirable tempareture increase caused by such cavitation bubbles, an ultrasonic irradiation method to suppress standing wave component has been proposed to avoid cavitation bubbles outside a HIFU focal region.[3)] In the previous study, the cavitation area generated outside focal region, observed by high-speed photography, was significantly reduced by a split-aperture irradiation method compared to continuous irradiation. In this study, to test the robustness of the proposed method, the focal point for generating cavitation bubbles was set 10 mm in front of the HIFU focal point, where an acoustic reflector to generate standing waves was located.

2. Material and Method

2.1 Experimental setup

Fig. 1 shows the experimental setup. A 2D array transducer (Japan Probe) with a diameter of 147.8 mm and a focal length of 120 mm was driven at 1MHz. The experiment was conducted in a degassed water (dissolved oxygen saturation of 20 to 30 %), and a HIFU exposure target was placed 10 mm toward the transducer from the HIFU geometric focal point as an acoustic reflector to generate standing waves. Either a sapphire glass 5 mm thick or a cover glass 0.13 – 0.17 mm thick was used as the target. An agarose gel with a concentration of 1 % was placed on the cover glass surface. As shown in Fig. 1, a high intensity pulse was focused 10 mm in front of the geometric focal point to generate cavitation bubbles in the prefocal region of the immediately following burst wave, focused to the geometric focal point. Cavitation bubbles generated on the glasses were observed with a high-speed camera (Photoron FASTCAM Mini WX100) at 1 kfps, backlit by laser with a pulse duration of 20 ns and a wavelength of 640 nm (Cavitar CAVILUX Smart). A difference image was obtained by subtracting the image just before the cavitation generation pulse reaches to the target. The difference image was binarized and the number of black pixels was counted to calculate the area of cavitation bubbles.

2.2 HIFU irradiation method

Fig. 2 shows the HIFU irradiation methods in the experiments. The 128 elements of the 2D array transducer were divided into two groups of 64 elements. Hereafter, they are referred to element 1 and element 2, respectively. In the continuous mode, ultrasonic irradiation was performed simultaneously and continuously from the elements 1 and 2. After irradiating a cavitation generation pulse at a total acoustic power of 930 W for 0.1 ms, a heating burst at 58 W for 75 ms followed. In the intermittent mode, elements 1 and 2 were driven simultaneously for 75 ms, pausing for 0.05 ms once every 0.1 ms. In the split-aperture mode, after the cavitation generating pulse exposure under the same condition, the heating burst was transmitted for 75 ms alternating the source between element 1 and 2 once every 0.05 ms. The total acoustic energy and the exposure time were kept the same in all modes.

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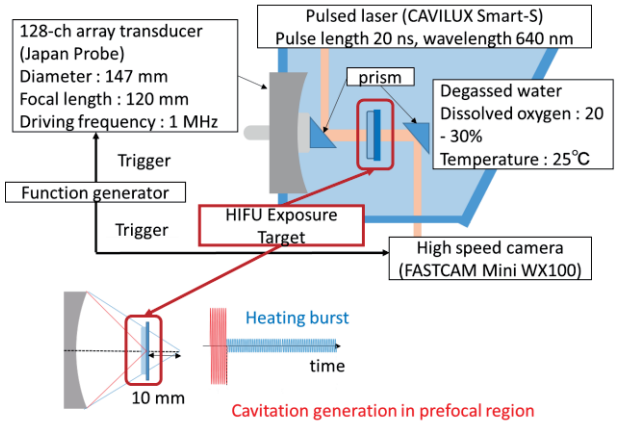

Fig. 1 Schematic of experimental setup.

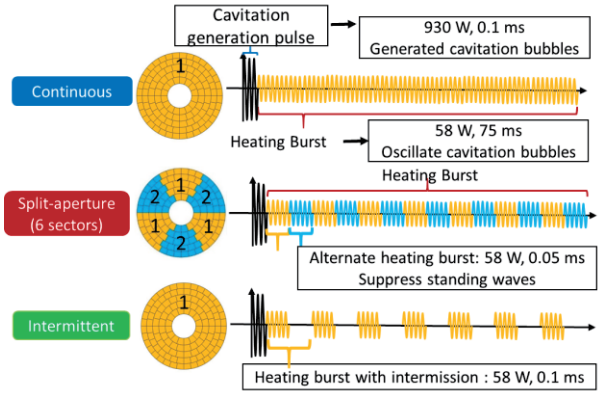

Fig. 2 HIFU exposure sequences and examples of aperture division.

3. Result and Discussion

Fig. 3 shows the temporal change of cavitation area. For both targets, the cavitation bubbles remaining on the target were most reduced by the split-aperture irradiation. As shown in Fig. 3(b), several different numbers of divisions in the split-aperture irradiation were compared in water on a sapphire glass. The amount of cavitation bubbles by the split-aperture method with 6 sectors was the smallest, although there was only small difference among the results by the split-aperture sequences in water on sapphire glass. In an agarose gel on cover glass as shown in Fig. 3(d), the cavitation area by the split-aperture method with 6 sectors was smaller than the half that with 2 sectors. The result indicates that the standing wave components were effectively suppressed by the split-aperture method with 6 sectors in the agarose gel on the cover glass.

The number of the division in the split-aperture should be chosen by also considering heating efficiency in the HIFU focal region.

4. Conclusion

In this study, after generating cavitation bubbles slightly outside the HIFU focal region, the amount of remaining bubbles by each irradiation method was compared. The result shows that the amount of cavitation bubbles was significantly suppressed by the split-aperture irradiation methods compared to the continuous and intermittent irradiation methods. The split-aperture transmission method will reduce the risk of skin burns caused by cavitation bubbles in a HIFU treatment.

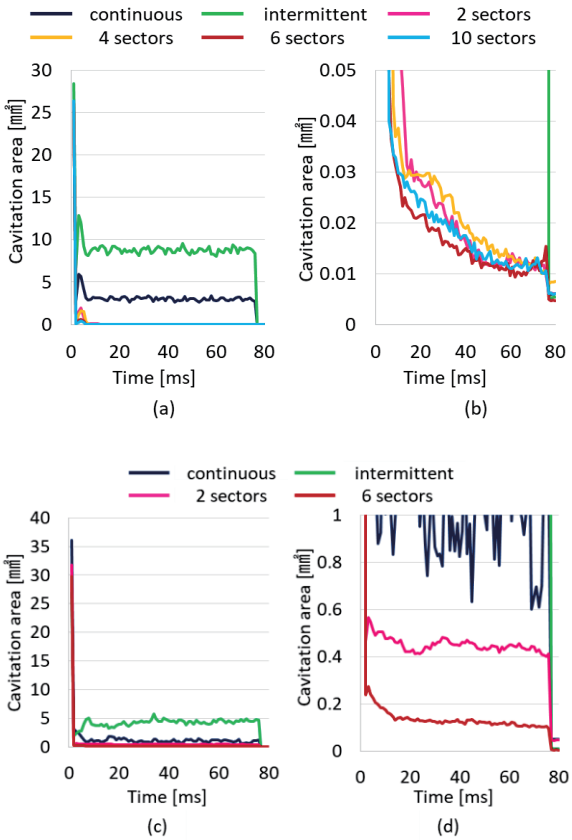

Fig. 3 Temporal change of cavitation area
(a) in water on a sapphire glass,
(b) magnified graph (a),
(c) in agarose gel on a cover glass, and
(d) magnified graph (c).

References

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