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Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 387-388
13-15 November, 2012

Efficient Generation of Cavitation bubbles in Gel Phantom by Dual-Frequency Ultrasound Exposure

生体模擬ゲル中での高周波重畳法によるキャビテーションの効率的な発生に関する研究

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1. Introduction

High intensity focused ultrasound (HIFU) treatment has been a subject of much interest. In HIFU treatment, ultrasound is generated outside the body and focused at the target tissue to treat it noninvasively.

Cavitation bubbles are known and utilized to enhance HIFU treatment.(1 In such HIFU treatment, firstly, a short (in the order of 10 μs to 1 ms) extremely high intensity ultrasound pulse is irradiated to generate cavitation bubbles in the target tissue, and immediately after that, they are irradiated with a long duration (in the order of 1 to 10 s) of moderately high intensity ultrasound waves to generate heat by their volume oscillation. The former and latter waves are called “Trigger pulse”and “Heating waves”, respectively.

In the HIFU treatment utilizing cavitation bubbles, the efficiency of generating them by the Trigger pulse is important. However, generating them by just increasing its intensity is difficult, because the negative peak pressure around focal area of HIFU, crucial for generating cavitation bubbles, is difficult increase due to nonlinear propagation.

In our previous study, “Dual-Frequency Ultrasound Exposure” method was suggested.2)

Fig.1 shows the schematic of this method, in which waveforms emphasizing either the positive-peak pressure or the negative-peak pressure are synthesized by superimposing second-harmonic onto the fundamental. These positive and negative peak enhanced waves are called “P waves” and “N waves”, respectively.

In this study, the behavior of the cavitation bubbles generated in the gel phantom by this method was observed and the temperature rise around focal area was measured.

2. Experimental and Setup

Fig.2 shows the experimental setup in this study. An array ultrasound transducer (Imasonic) and a gel phantom are placed in a PMMA water tank. The phantom consisted of a polyacrylamide (PAA) gel including 22.5 % of bovine serum albumin (BSA). The focus was located in the gel. A high-speed camera was set to observe the behavior of the cavitation bubbles. The transducer had 128 elements with an equal area, a center frequency of 1.0 MHz, and outer and inner diameters of 100 and 36 mm, respectively. The water tank was filled with deionized water, whose DO level and temperature were maintained 65-75 %, and 36 ℃, respectively.

A thermocouple was set in the gel to measure the temperature of the focal area. However, a certain small offset from the focus was given to the thermocouple because it is difficult to measure the correct temperature if the cavitation bubbles contact the thermocouple,.

The Trigger pulse was irradiated for 125 μs and three different types of sequences were used. In the first sequence, the N waves were employed for 125 μs. In the second sequence, the N and P waves were employed in the earlier and later 62.5 μs, respectively. The Heating waves were irradiated for 5 s, at 2 kW. The fundamental and second-harmonic frequencies were 0.8 and 1.6 MHz, respectively.

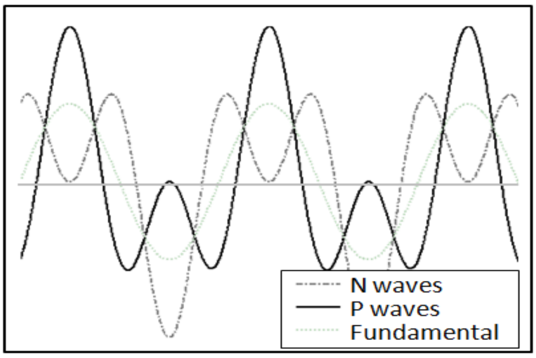

Fig.1 The image of Dual-Frequency Ultrasound Exposure

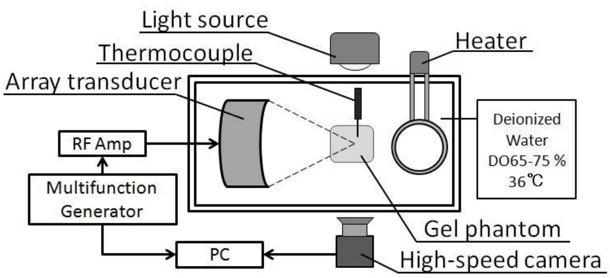

Fig.2 The experimental system

3. Result and Discussion

Fig.3 shows the relation between the ultrasound intensity and the amount of generated cavitation bubbles. The amount of cavitation bubbles was calculated by the number of the pixel in the high-speed camera pictures. The NP and NN indicate the sequences that employed NP and NN as Trigger pulses. In the two types of sequences, the amount generated by the NP was significantly more than the NN.

Fig.4 shows the pictures of the high-speed camera at the NN and NP. There are arranged in the time series and the ultrasound intensities of the Trigger pulse and Heating waves were 20 and 2 kW/cm^2, respectively. In the NP, the cavitation bubbles seem to have grown up toward the transducer.

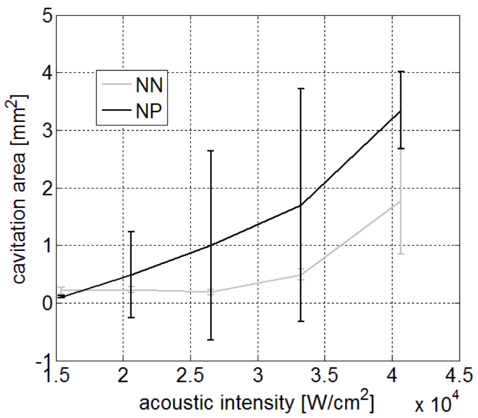

Fig.3 Relation between generated amount of cavitation bubbles and ultrasound intensity

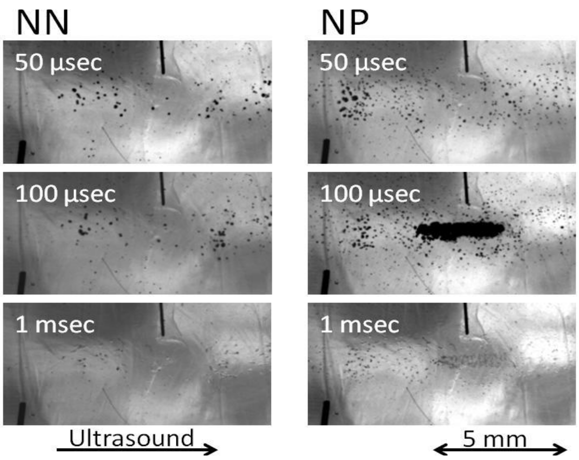

Fig.4 High-speed camera pictures

In NP, firstly, the cavitation bubbles were generated by N waves. If cavitation bubbles are once formed, their surfaces will become pressure-releasing surfaces. When the P waves are irradiated toward such surfaces, the reflected waves will have the reversed phase and become extremely high intensity N waves which should further generate the cavitation bubbles at a high efficiency and make the bubble cloud grow toward the transducer.

Fig.5 shows the temperature rise around the focal area for the three different types of sequences. “Heating only” indicates the sequence wihtout a Trigger pulse. In this sequence, few cavitation bubbles were generated, thus, the temperature rise was the lowest of the three.

On the other hand, the temperature rise by NP was the highest of the three. As shown in Fig.4, in the NP, the cavitation bubbles were generated much more than NN, therefore, these generated cavitation bubbles remained through the duration of the Heating waves. The temperature around the focal area was thereby risen at high efficiency.

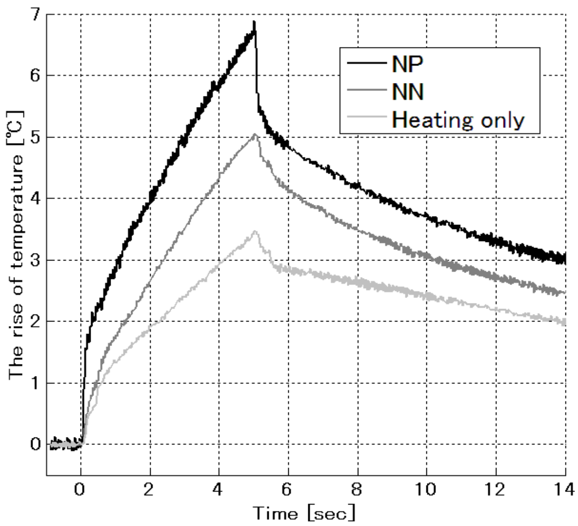

Fig.5 The rise of temperature

4. Conclusion

In this study, the behavior of cavitation bubbles in the gel phantom was observed and the temperature rise around the focal area was measured. The cavitation bubbles were generated most efficiently by the NP and the resulting temperature rise was also the highest in the three sequences.

Acknowledgement

This research was supported by Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science(JSPS).

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