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Enhancement of Localized Heating by Ultrasonically Induced Cavitation in High Intensity Focused Ultrasound Treatment

強力集束超音波治療におけるキャビテーションを利用した局所加熱作用の増強

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1. Introduction

There are reports ultrasonically induced cavitation bubbles locally enhance the heating in the tissue in High Intensity Focused Ultrasound (HIFU) treatment [1]. In this study field, the challenge is how to create, and control the cavitation microbubbles.

In this experiment, the chicken fillets are used as a tissue mimicking phantom. First, a high intensity burst above the cavitation threshold is focused at the tissue in order to trigger cavitation. Right after that, the CW ultrasound, at an intensity level and with duration, typical for conventional HIFU ablation is irradiated. By using this method, the acoustic energy of HIFU is converted to heat efficiently at the cavitation site, and the tissue around the site is coagulated effectively. In this experimental process, subharmonics from cavitaing bubbles is detected, and the relationship between the 1/2 subharmonic signal amplitude and the coagulation volume after the HIFU exposure is investigated.

2. Experimental procedure

Fig. 1 shows the experimental setup. An air-backed ultrasound transducer consisting of a spherical PZT ceramic element was placed in a PMMA water tank. Both diameter and focal length of the PZT element were 60 mm. The resonance frequency of the transducer was 1.08 MHz. The focus was located at a depth of 10 mm from the surface of the tissue. A hydrophone was located 20 mm above the focus to pick up the acoustic emission. The water tank was filled with deionized and degassed tap water. The temperature of the water was kept near body temperature, 36-37°C.

Fig. 2 schematically shows the waveform used in this experiment. First, high intensity burst (named as “triggering pulse”) was irradiated for 100 μs. Immediately after the triggering pulse, low

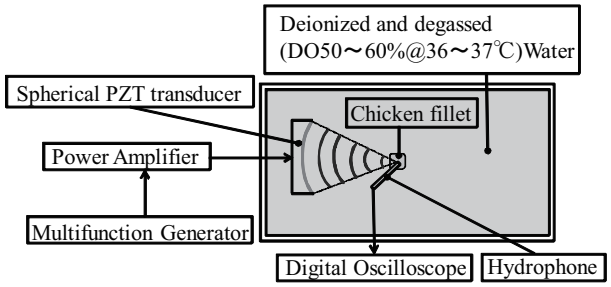

Fig. 1 Schematic of the experimental setup.

intensity CW ultrasound (named as “sustaining pulse”) was irradiated for 100 ms in order to sustain the cavitation for detection. During the sustaining pulse was irradiated, the 1/2 subharmonic signal amplitude in the acoustic emission from the focus was analyzed [2]. The intensity of the triggering and detecting pulses were 3.23 kW/cm^2, and 15.9 W/cm^2, respectively. Immediately after subharmonic detection, medium intensity CW ultrasound (named as “heating waves”) was irradiated for 5 s. The relationship between the 1/2 subharmonic signal amplitude and the coagulation volume after the exposure was investigated. The same procedure was repeated 9 times. Only heating waves without a triggering pulse cannot make the tissue coagulate. **Fig. 3** shows an example of the FFT spectrum of the detected acoustic emission, and the 1/2 subharmonic signal amplitude.

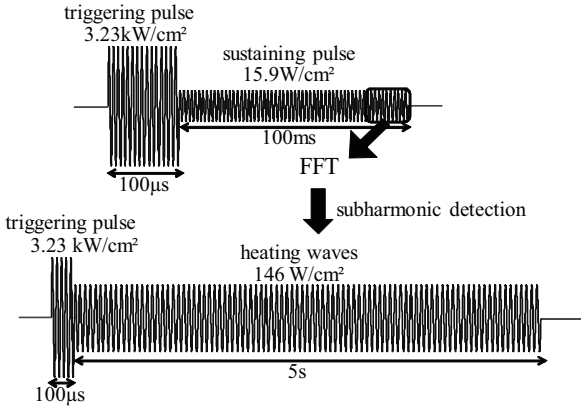

Fig. 2 Schematic of the waveform

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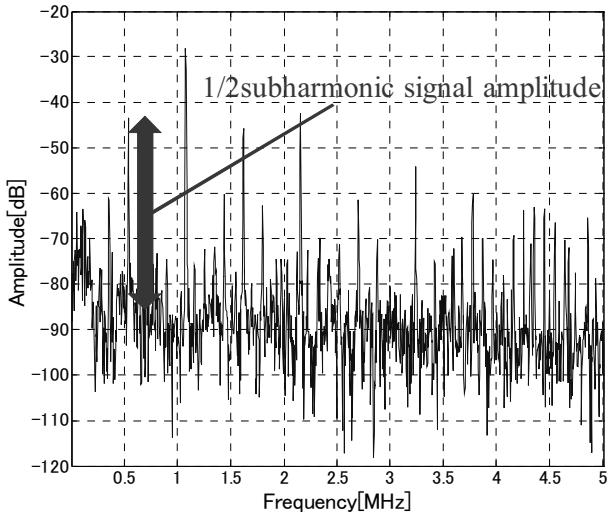

Fig. 3 Example of FFT spectrum of acoustic emission and 1/2 subharmonic signal amplitude

3. Results and discussion

Fig. 4 shows the relationship between the 1/2 subharmonic signal amplitude and the coagulation volume produced by each exposure experiment.

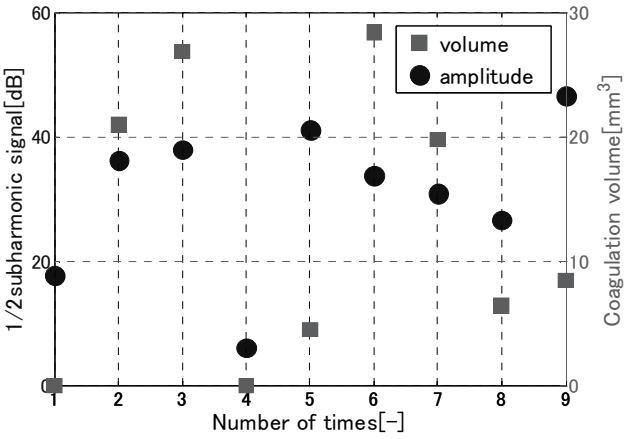

Fig. 4 Relationship between 1/2 subharmonic signal amplitude and coagulation volume

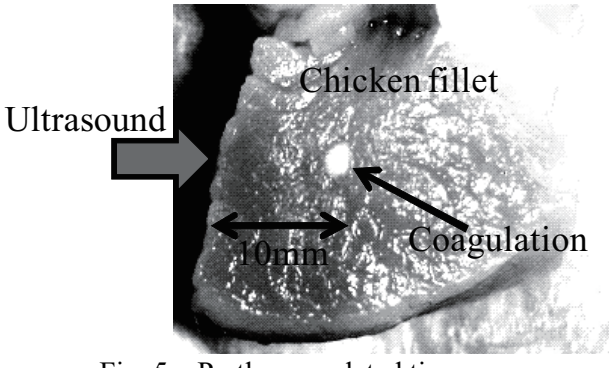

Fig. 5 Partly coagulated tissue

Fig. 5 shows a photograph of the coagulated chicken tissue after the last exposure experiment.

The 1/2 subharmonic amplitude at the first and fourth experiments was relatively lower (17.8 dB, 6.1dB respectively). In these cases, the tissue was not coagulated after by heating waves. In the other experiments, the 1/2 subharmonic amplitude larger than 25 dB was detected. In these cases, the chicken tissue was coagulated although the coagulation volume was differed significantly. At the first and fourth experiment, the quantity of cavitating bubbles seems to have been not enough to enhance the heating. It is consistent with the 1/2 subharmonic amplitude lower than those in the other experiments.

The results indicate that we could predict whether the tissue will be coagulated or not by detecting the 1/2 subharmonic signal before heating exposure, that is, we could optimize the triggering pulse to generate the sufficient cavitating bubbles before the heating exposure.

As shown in Fig. 5, the shape of the coagulation region was spherical, not ellipsoidal as those produced with normal HIFU exposure alone. This indicates that cavitating bubbles were well localized at the focal spot of the triggering pulse, and enhanced the heating at a heating wave intensity lower than to produce coagulation by itself.

4. Conclusion

The tissue was coagulated effectively with the triggered HIFU sequence. Before irradiating the heating waves which were not likely to coagulate the tissue by themselves, irradiated was the triggering pulse, which was a high intensity burst to generate cavitating bubbles in the tissue at focus. The experimental results indicated that the generated bubbles enhanced the heating locally and efficiently. The results also suggest that we will be able to optimize the triggering pulse by detecting the acoustic emission from cavitating microbubbles during the sustaining pulse at intensity and duration lower and shorter than the heating waves.

5. References

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2. S.Yoshizawa, et al: Med. Biol. Eng. Comput.**47** (2009) 851–860