3J1-2

Effect of Ultrasonic Focal Scanning Sequence on Cavitation Generation in Cavitation-enhanced Ultrasonic Heating

気泡援用超音波加熱における気泡生成に対して焦点走査シーケンスが及ぼす影響

Kohei Ueda[1‡], Shin-ichiro Umemura[1,3], and Shin Yoshizawa[2,3]
([1] Grad. School of Biomed. Eng., Tohoku Univ.; [2] Grad. School of Eng., Tohoku Univ.; [3] SONIRE Therapeutics)
上田 晃平 [1‡], 梅村 晋一郎 [1,3], 吉澤 晋 [2,3]
([1] 東北大院 医工, [2] 東北大院 工, [3] ソニア・セラピューティクス)

1. Introduction

High-intensity focused ultrasound (HIFU) is a noninvasive treatment method of cancer. In this method, ultrasound is focused from outside body onto the tumor tissue which should be coagulated through temperature rise. However, there is a problem of long treatment time, which can be solved by improving the heating efficiency.

In a focal region of HIFU, cavitation bubbles can be generated by a highly negative pressure. Such bubbles enhance ultrasonic heating[1)], and the heating efficiency should thereby be improved. In this study, the HIFU exposure sequence named "trigger HIFU sequence[2)]" is used to achieve such cavitation-enhanced ultrasonic heating. This sequence consists of two types of ultrasonic exposure. A high-intnsity short pulse called "trigger pulse" is irradiated first to generate cavitation bubbles. Then, a low-intensity long burst called "heating burst" follows to vibrate cavitation bubbles and enhance the heating. In addition, through scanning a focal spot in tens of micro seconds, it is possible to heat the tissue between the scanned focal spots by heat conduction. We have investigated a hexagonal focal spot scanning sequence and it was also applied to sonodynamic therapy[3)].

In this study, two types of experiments were performed to investigate the effect of inter-focal distance in the hexagonal scanning sequence. One was observing bubbles behavior using an hybrid phantom, called "sliced chicken phantom", consisting of chicken breast tissue and an agarose gel (Experiment 1). Another was comparing coagulation regions using blocks of chicken breast tissue (Experiment 2).

2. Materials and Method

2.1 Experimental Setup

Figs. 1 and **2** show the experimental setup and the sliced chicken phantom, respectively. A 2D array transducer had 128 elements at 1 MHz, and a diameter and focal length of 147.8 mm and 120 mm, respectively. The sliced chicken phantom was made by inserting a slice of chicken breast tissue about 3 mm in thickness into a 0.5% agarose gel. The phantom and a block of chicken breast tissue were placed in degassed water (dissolved oxygen saturation of about 20-25%). Cavitation clouds generated in the sliced chicken phantom were backlit by pulsed laser and observed with a high speed camera.

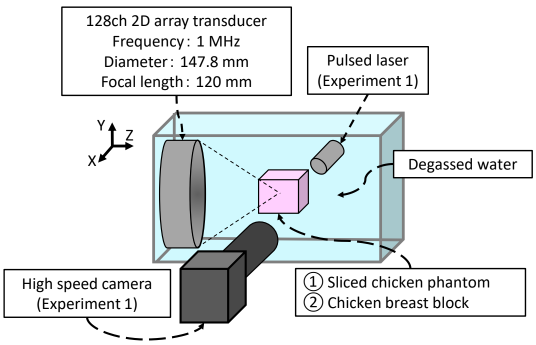


Fig. 1 Experimental setup.

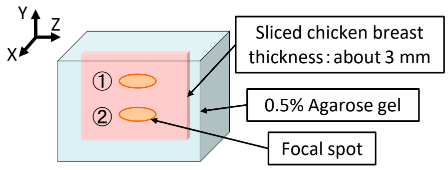
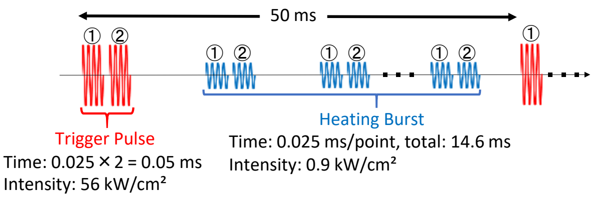


Fig. 2 Sliced chicken phantom.

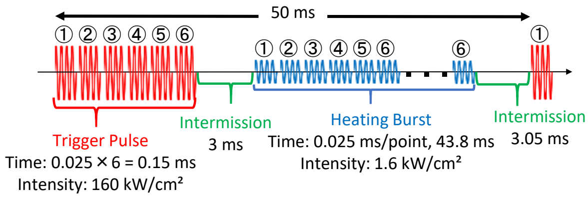
2.2 HIFU exposure sequences

Fig. 3 shows the HIFU exposure sequences. Focal spots were set at each vertex of a regular hexagon. Both trigger pulses and heating bursts were focused to the vertices in the same order in the sequence. In Experiment 1, HIFU was focused to the two neighboring spots among the six spots. The inter-focal distances were 2, 2.5, 3, and 5 mm. The trigger pulses were focused to 4 mm beyond the geometric focal plane considering shock scattering[4)].

A cycle of the sequence for 50 ms was repeated 4 and 300 times, resulting in a total time of 0.2 and 15 s in Experiment 1 and 2, respectively. In Experiment 1, the intensity of trigger pulse, chosen to generate bubbles in the chicken tissue and not in the gel, was 56 kW/cm². That of heating burst was 0.9 kW/cm² In Experiment 2, these intensities were chosen to match those in the phantom, considering the attenuation in the chicken breast tissue. The intensity of trigger pulse and heating burst was 160 kW/cm² and 1.6 kW/cm² in water, respectively.



(a)



(b)

Fig. 3 HIFU exposure sequences.
(a) In Experiment 1. (b) In Experiment 2.

3. Result and Discussion

Fig. 4 shows examples of subtracted high speed images of the sliced chicken phantom. It is considered that the gray cloudy areas in the images correspond to the shadow of cavitation clouds generated in the sliced chicken breast. Two separated cavitation areas were observed even with a short inter-focal distance such as 2 mm.

Fig. 5 shows the gross pathology of the coagulated chicken tissues. The focal plane was set at a depth of about 20 mm from the surface of the block. With inter-focal distances of 2 and 2.5 mm, the coagulation region corresponding to the size of the scanned region was observed. However, only small coagulation region was obtained with the distance of 3 mm.

The result of high speed observation showed that the shielding effect of bubble clouds did not significantly suppress the cloud generation at the adjacent focal spot even with when the inter-focal distance was short. On the other hand, it is possible to utilize bubbles generated at the adjacent spots with the shorter inter-focal distance. In the experiments, such a positive effect of the short inter-focal distance probably enhanced the ultrasonic heating with inter-focal distance of 2 and 2.5 mm.

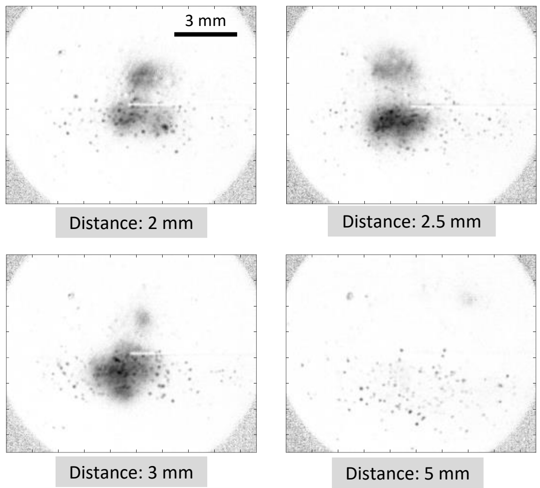


Fig. 4 Subtracted high speed images of sliced chicken phantom

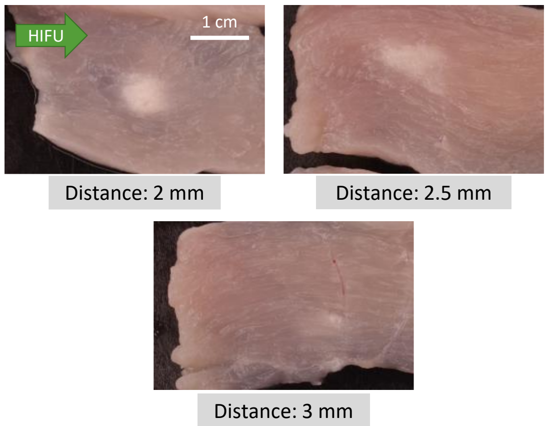


Fig. 5 Gross pathology of coagulated chicken tissue

4. Conclusion

In this study, the effect of inter-focal distance in bubble generation with a hexagonal focal scanning sequence was investigated. The result of the experiments showed that there was a range of the inter-focal distance such that the bubbles generated at the adjacent spots should positively contribute to the enhancement of the ultrasonic heating without significantly suppressing the cavitation cloud formation.

References

1. R. G. Holt and R. A. Roy: Ultrasound Med. Biol. **27** (2001) 1399.
2. R. Takagi, S. Yoshizawa, and S. Umemura: Jpn. J. Appl. Phys. **49** (2010) 07HF21.
3. Y. Horise et al.: Front. Pharmacol. **10** (2019) 545.
4. A. D. Maxwell, W. Tzu-Yin, C. A. Cain and J. B. Fowlkes: J. Acoust. Soc. Am. **130** (2011) 1888.