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Effect of Controlled Offset of Focal Position in Cavitation Enhanced High Intensity Focused Ultrasound Treatment

キャビテーション気泡生成位置を考慮した焦点位置制御が加熱凝固領域に与える影響

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1. Introduction

High-intensity Focused Ultrasound (HIFU) treatment is a non-invasive therapy, which focuses ultrasound energy to coagulate target tissue such as cancer.[1)] Due to the nature of ultrasound, the treatment can be conducted non-invasively so as to cauterize tissue only in the focal zone. Hence, it will reduce the impact of physical and mental stresses on the patient. However, there are some drawbacks of HIFU treatment such that the treatment needs longer time especially for larger size cancer. This is due to the small coagulation capability in a single exposure. In order to solve this problem, many studies proposed the usage of the cavitation bubbles in order to enhance the heating effect so that the treatment period will become shorter.[2)] However, it is difficult to control and generate cavitation bubbles in the desired place and time. For example, the cavitation bubble cloud generated by focused ultrasound tends to grow backward, which may cause a spatial mismatch when it has been intended to enhance the heating effect of the focused ultrasound. In this paper, the influence of the intentional offset between the focal points for generating cavitation and heating on the coagulation capability is studied.

2. Materials and methods

2.1. Multi-Triggered HIFU

"Triggered HIFU" is a sequence to utilize cavitation bubbles to enhance ultrasonic heating.[3)] It consists of two kinds of waves. The first one is a short pulse at an extremely high-intensity, named as "Trigger Pulse", which generates the cavitation bubbles first. It is immediately followed by a long pulse at a relatively low-intensity, named as "Heating Waves", which vibrates the cavitation bubbles to enhance the heating effect.[4)]

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2.2. Controlled offset of focal points

The electronic focal point of the Triggered Pulses was shifted forward by 0-10 mm from the geometrical focal point of an array transducer (Imasonic) at 1 MHz while the focal point of the Heating Waves was kept the same.

2.3. HIFU sequences

Fig. 1 shows the Triggered HIFU sequence. The focus was laterally scanned also electronically at each corner of a regular hexagon 3 mm each side.[5)] It stayed at each corner for 25 μs. The Trigger Pulses and the Heating Waves had an intensity of 64 and 2.2 kW/cm^2 and a subtotal duration of 150 μs, and 64 ms, respectively. Ultrasonic imaging was performed at the end of each sequence. This sequence of ultrasound exposure was repeated 120 times, resulting in a grand total duration of 16.5 s.

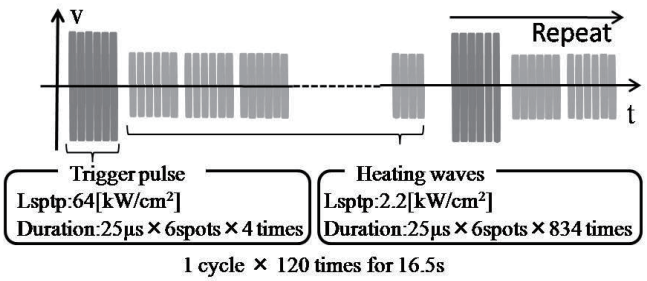

Fig. 1 Irradiation sequence of Triggered HIFU

2.4. Experimental setup

Fig. 2 shows the setup of the experiment in a water tank. The water was degassed (DO: 20-30%) and kept at 36 degrees. The piezo-composite array transducer had both outer diameter and geometrical focal length of 120 mm. It was connected to 128-channel staircase voltage amplifiers (Microsonic), controlled by a PC. An

ultrasound imaging system (Verasonics) and a sector array probe (UST-51205, Hitachi Aloka) inserted in the central hole of the transducer ware used to monitor the tissue and the cavitation bubbles. Degassed chicken breast was used as the sample for the ultrasound irradiation.

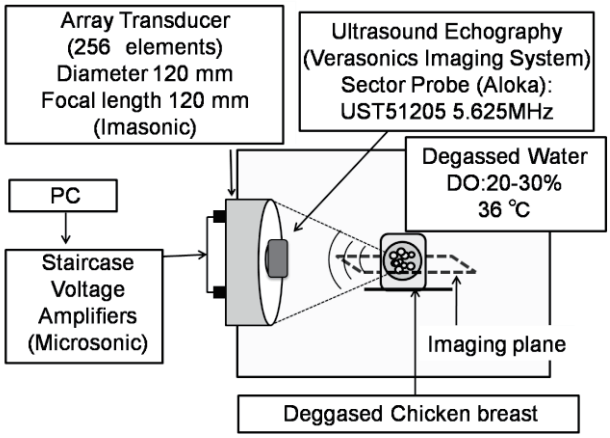

Fig. 2 Schematic of experimental setup

3. Results and Discussion

Fig. 3 shows the cross-sectional pathology of the coagulated chicken breast tissue and its brightness distributions of three experiments of the same sequence of HIFU from the left. The focal point offset was 0 mm (a) and 10 mm (b). The peak of brightness is significantly shifted backward with no focal point offset. In contrast, high brightness distribution is more uniform in the depth direction and has more distinctive boundaries, with a focal point offset of 10 mm.

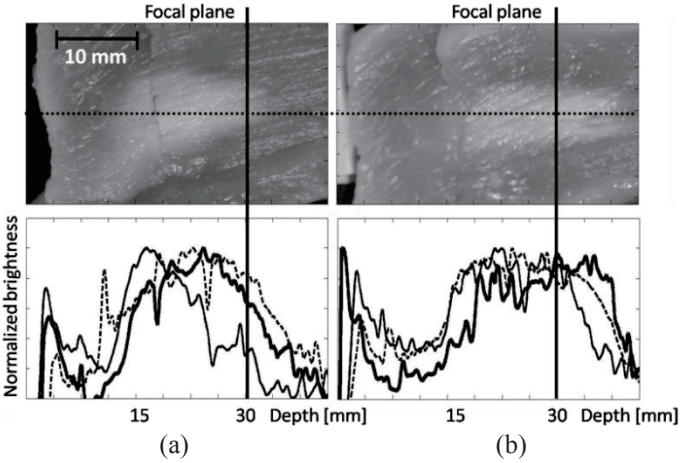

Fig. 3 Brightness in cross-sectional pathology of coagulated chicken breast tissue with focal point offset of (a) 0 mm and (b) 10 mm. The geometrical focal plane is shown by a solid line.

Fig. 4 shows B-mode images of the chicken breast tissue during the Triggered HIFU sequence. The position of the generated microbubble cloud is shifted by 5-10 mm backward with no focal point offset. In contrast, it is about on the geometrical focal plane with a focal point offset of 10 mm. This clearly explains the obtained results shown in **Fig. 3**. However, the coagulated area seen in **Fig. 3** is slightly longer in the depth direction than the microbubble cloud seen in **Fig. 4**.

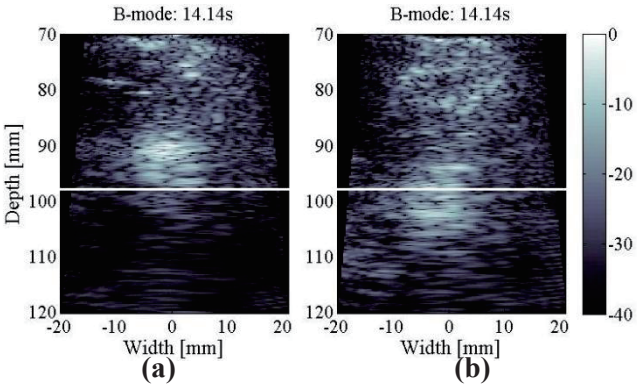

Fig. 4 Real-time B-mode image of cavitation bubbles in chicken breast tissue with focal point offset of (a) 0 mm and (b) 10 mm. The geometrical focal plane is shown by a white line.

4. Conclusion

With an electronically controlled focal point offset of 10 mm forward from the geometrical one, the coagulation areas with more distinctive boundaries were created more uniformly in the depth direction. This approach will make HIFU treatment more accurate. The effect of the controlled focal point offset was also confirmed by the position of generated microbubble cloud in the B-mode images taken during the Triggered HIFU sequence. However, it seems to be difficult to predict the size of coagulation area from that of the microbubble cloud. Further studies are needed to predict or estimate the size of the coagulation area.

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