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High Speed Observation of Multiple Cavitation Cloud Behavior Induced by HIFU
強力集束超音波によって生成した複数のキャビテーション群の高速度撮影

Yuta Inaba[1‡], Tatsuya Moriyama[1], Shin Yoshizawa[1] and Shin-ichiro Umemura[1]
([1] Tohoku Univ.,)
稲葉脩太 [1‡]，森山達也 [1]，吉澤晋 [1]，梅村晋一郎 [1] （[1] 東北大）

1. Introduction

In HIFU (High Intensity Focused Ultrasound) therapy, ultrasound is focused on target tissue for coagulation. This method is attracting attention as noninvasive therapeutic modality, but it has a problem of long treatment time. Ultrasonically induced cavitation is known to enhance tissue heating.[1)] To improve the efficiency of the treatment, we have been developing a method of coagulating a large region at once by utilizing multiple clouds of acoustic cavitation and named it “triggered HIFU”, in which an extremely intense focused ultrasound pulse to initiate cavitation (trigger pulse), immediately followed by moderate-intensity long-burst focused ultrasound for heating (heating waves), is used.[2)]

For further improvement of coagulation throughput, non-spherically focused heating waves, forming an elongated focus to cover all the cavitation clouds which have been created by multiple trigger pulses, were proposed. The cavitation cloud distribution as well as the heating wave focus may be enlarged either parallel or perpendicular to the direction of ultrasound propagation.

For the reproducible efficiency of this sequence, it is important to ensure whether cavitation clouds can be generated at intended positions and whether they can survive until the heating waves reach there. In this study, a high-speed camera was used to observe such behavior of cavitation clouds[3)] and optimize the sequence for its coagulation performance.

2. Materials and methods

A multifunction generator (WF1974, NF) was used to generate and modulate sinusoidal waves. The waves were input to RF amplifiers (100A2, E&I) to drive a focused array transducer (Imasonic) having 128 equal area elements, a central frequency of 1.0 MHz, outer and inner diameters of respectively 100 and 36 mm, and a radius of curvature of 100 mm.

Ten to sixteen transducer elements were electrically combined and connected to either one of the ten amplifiers. The behavior of cavitation clouds was recorded using a high-speed video camera (Phantom V7.3, Vision Research).

A polyacrylamide gel (PAA) was submerged in degassed water (DO 30~40%) and exposed to ultrasound. First, a trigger pulse was irradiated for 100 μs to each one of the four focal points at ±1.4 mm (x=±1.4), ±4.2 mm (x=±4.2), respectively, which were laterally steered by changing the driving phases of the combined groups of elements. This cycle was repeated for 10 times, resulting in the total irradiation time for each focal point of 1 ms. Right after these cycles, heating waves were irradiated for 10 s with a widened focus covering the all four focal points. Cavitation clouds in the gel were observed from their generation by the trigger pulses to their reaction to the heating waves. The thermal coagulation performance of this sequence was confirmed by an experiment with chicken breast tissue.

3. Results

The positive pressure field of the widened-focus heating waves, measured with the hydrophone, is shown in **Fig. 1**, where the origin is the geometric focal point of transducer, and the x axis is perpendicular to the ultrasound propagation.

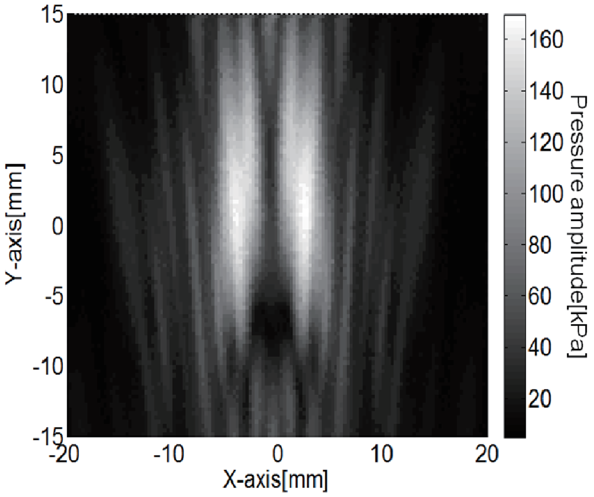

Fig.1 Measurement of heating waves pressure

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y_inaba@ecei.tohoku.ac.jp

Figure 2 shows the four cavitation clouds. The upper shows those during a trigger pulse focused at -4.2 mm (x=-4.2), and the lower shows those during the heating waves. The intensity of the trigger pulses and heating waves were 30 kW/cm^2 and 0.5 kW/cm^2, respectively.

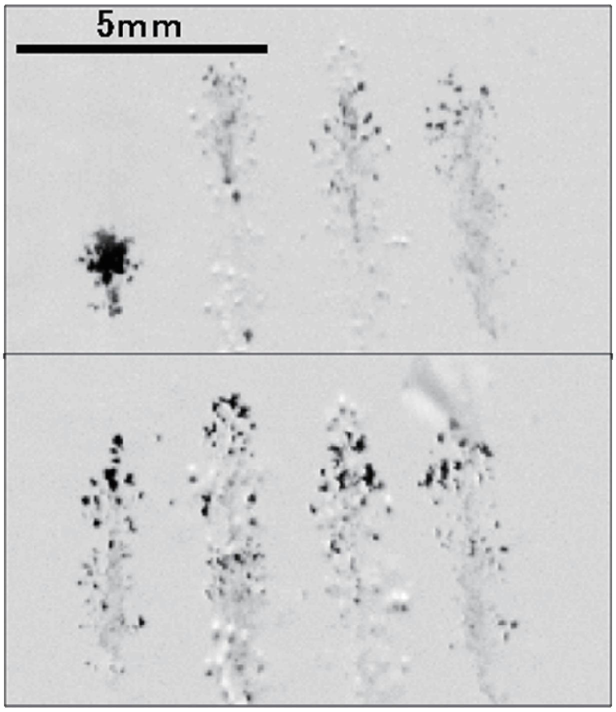

Fig. 2 Optical change in gel phantom on ultrasound sequence

The result of the coagulation experiment of chicken tissue is shown in **Fig.3**. A large contiguous coagulation area is observed. Coagulation may have been extended from each cavitation cloud and connected together to form such a contiguous area.

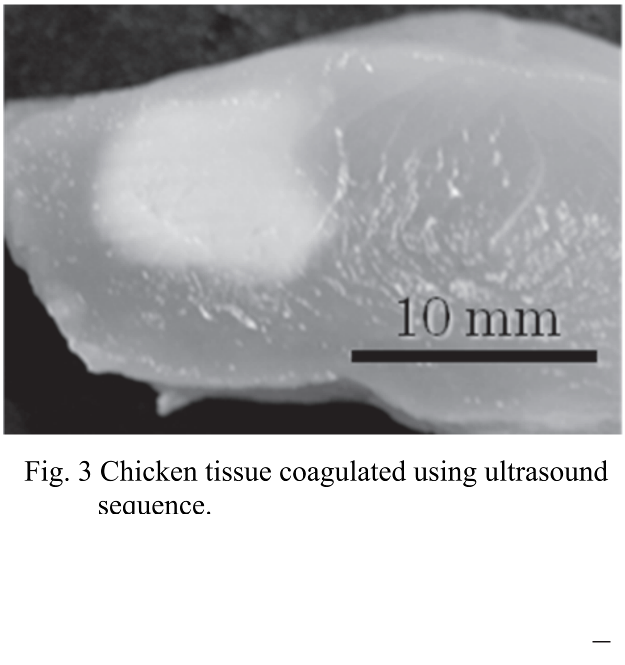

Fig. 3 Chicken tissue coagulated using ultrasound sequence.

4. Discussion

For the reproducible efficiency of the sequence utilizing cavitation clouds, the following three points are important. Cavitation clouds should be generated at objective positions by the triggering pulses. The generated cavitation clouds should survive until the heating waves reach there. The heating waves should cover all the cavitation clouds. These were confirmed by observing the behavior of cavitation clouds in a gel phantom with a high-speed camera.

In this experiment, cavitation clouds were generated at +1.4 mm, -1.4 mm, +4.2 mm, -4.2 mm in sequence. This sequence has been chosen by considering the nature of a bubble as an acoustic reflector and the effect of the side lobes of a steered focal beam to sustain cavitation clouds,[4)] but it may be optimized by further study.

The focus of the heating waves was widened by carefully tuning the driving phases of the transducer elements for this particular experiment. An automatic algorithm to generate the optimum driving phases will be necessary for using this method widely in practice.

The coagulation experiment with chicken tissue proved that this approach is useful to enlarge a coagulation volume in the perpendicular as well as parallel direction of ultrasound propagation, suggesting that it can be enlarged three dimensionally if needed.

5. Conclusion

The behavior of multiple cavitation clouds, generated by the trigger pulses and sustained until and during the heating waves, was observed with a high-speed camera, and thier role to simultaneously form an enlarged coagulation volume reproducibly was confirmed.

Acknowledgment

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