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Study on Control of Treatment Size in Bubble-Enhanced High-Intensity Focused Ultrasound Using Radio-Frequency Echo Signal

気泡援用超音波治療におけるRFエコー信号を用いた治療領域の制御

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1. Introduction

High-Intensity Focused Ultrasound (HIFU) treatment is a noninvasive method of treatment in which ultrasound is generated by a transducer set outside the body and focused on a target tissue such as cancer inside the body to be thermally coagulated. According to previous study, cavitation bubbles are known to accelerate therapeutic effect of HIFU treatment and “trigger HIFU sequence” can make good use of such bubbles1). Its sequence use two types of waves. One is a high intensity short pulse (“trigger pulse”) to generate cavitation bubbles. The other is a relatively low intensity burst (“heating burst”) to sustain the bubbles and accelerate the heat generation. In order to enhance the safety and accuracy of bubble-enhanced HIFU treatment, it is desirable to monitor thermal lesion in real-time and to give the operator such information as a feedback.

In this study, the therapeutic ultrasound scattered by the thermal lesion potentially containing bubbles is regarded as a feedback element and the therapeutic ultrasound is stopped automatically by detecting the change in such signal due to the thermal lesion formation. The objective is to control the length of coagulated region in front of the focal point.

2. Materials and Methods

2.1 Experimental setup and Sequence

Fig.1 shows a schematic of the experimental setup. A chicken breast soaked with degassed saline was submerged in a tank containing degassed water. HIFU was generated by a 256-element array transducer (Imasonic) with both outer diameter and geological focal length of 120mm. A sector array probe (UST-52105, Aloka) was set in the central hole of the 256-elemernt array transducer and connected to a programmable ultrasound imaging system (Vantage, Verasonics). The imaging plane was set so that it contained the axis as well as focal point of HIFU.

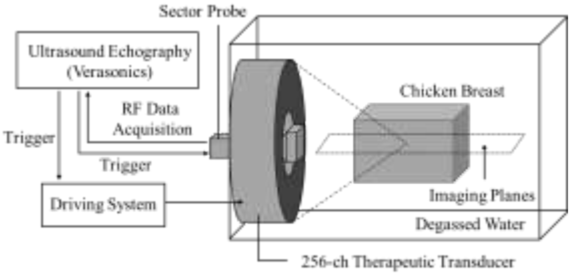

Fig.1 Schematic of experimental setup

The sequence of therapeutic ultrasound and imaging ultrasound is shown in **Fig.2**. The upper half part shows the therapeutic ultrasound sequence. A trigger pulse exposed for 100 μs at an intensity of 60 kW/cm^2 and a heating burst exposed for 50 ms at an intensity of 2 kW/cm^2. The other half part shows the imaging ultrasound sequence. RF data acquisition executed two times during and after the therapeutic ultrasound exposure, respectively.

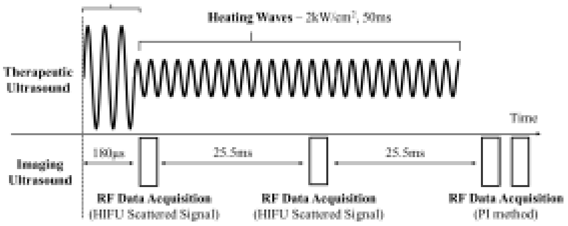

Fig.2 Sequence of therapeutic and imaging ultrasound

2.2 Ultrasound Imaging

Two kinds of approach to acquire RF data were employed. One is RF data during therapeutic ultrasound exposure with a receive frequency of 3.75 MHz to judge whether or not to stop exposure. The other is RF data after therapeutic ultrasound exposure to watch cavitation behavior. The latter

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adopted pulse inversion2) (PI) method with transmit and receiving frequency of 1.88 and 3.75 MHz, respectively, for selectively detecting the nonlinear echoes from bubbles in the resonance size.

2.3 Method of RF data analysis

In this study, power spectra of RF data during HIFU exposure was used to automatically judge whether the HIFU exposure should be stopped or not. **Fig.3 (a)** shows RF data in a channel of the sector probe and **Fig.3 (b)** shows the power spectra of the RF data after receive beamforming was processed. The threshold for a certain signal to properly stop the HIFU exposure was needed to set. It was assumed that the second harmonic signal component of HIFU should be generated by bubbles in the resonance size such as cavitation bubbles. In other words, the increase in the second harmonic signal component can be interpreted as the increase in the number of cavitation bubbles. Therefore, a threshold was set for both the ratio and difference between the second harmonic signal component of HIFU (2.0 MHz) to the fundamental component (1.0 MHz), aiming to increase the sensitivity for detecting bubbles and reduce the influence of power spectral noise. Firstly, both difference and ratio mostly preserved each maximum value for 2.5 s. At 2.5 s after the start of HIFU exposure, the threshold for difference was set to twice its maximum value during the previous 2.5 s, and the threshold for ratio was set to 6 dB higher than its maximum value during the previous 2.5 s. The HIFU exposure was stopped within 0.1 s when either of the two thresholds was exceeded.

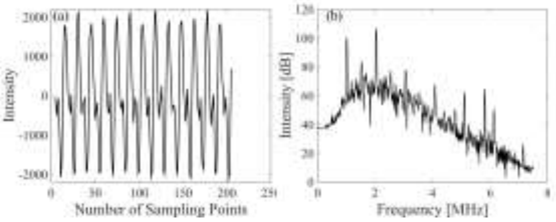

Fig. 3 Process of RF data analysis

(a)HIFU scattered signal

(b)power spectra of RF data

3. Results and Discussion

Fig.4 shows the actual coagulated region, in which the HIFU propagated upward. The coagulation size in front of the focal point was chosen as a factor to be considered in the judgement whether this method can properly control the HIFU induced thermal coagulation or not. **Fig.5** shows the obtained results, compared with a conventional method in which the HIFU exposure duration was determined in advance and fixed. The fluctuation in coagulation size by the proposed method seen in **Fig. 5** is significantly smaller than the conventional method. This suggests that the proposed method is useful for automatic control of coagulation size.

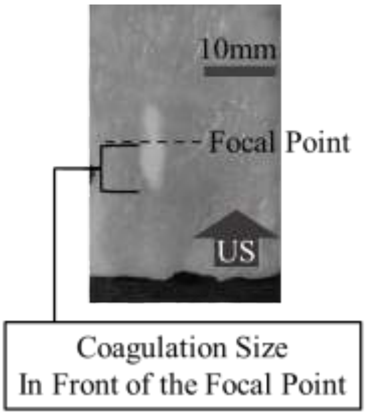

Fig. 4 Slice of sample after HIFU exposure

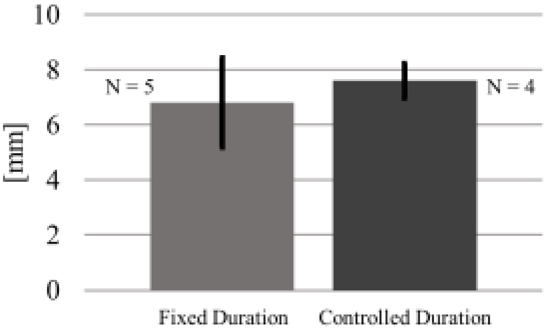

Fig. 5 Treatment size in front of the focal point

4. Conclusion

This study demonstrated that the fluctuation of coagulation size in front of the focal spot can be reduced by using the temporal change in the power spectra of the scattered RF signal. The result suggests that the proposed method improves the reproducibility of the coagulation size due to multiple exposures in the bubble-enhanced HIFU treatment. This study may enhance the safety and accuracy of such treatment.

References

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