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Ultrasound Imaging of Cavitation Bubbles by Triplet Pulse Sequence with Reduction of Therapeutic Ultrasound Noise

治療用超音波ノイズ低減手法を用いた 3 パルス法による気泡の超音波イメージング

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1. Introduction

High-intensity focused ultrasound (HIFU) is a minimally invasive therapeutic modality. It can treat cancer by irradiating focused ultrasound from outside the body. The efficiency of a HIFU treatment can be improved by cavitation bubbles. Since bubbles can be monitored by ultrasound imaging in real time, ultrasound imaging is appropriate as an image guidance for a HIFU treatment using cavitation bubbles. The treatment is usually monitored during the HIFU intermission to avoid the ultrasound interference, but this causes the increase of the overall treatment time. In order to make ultrasonic monitoring during HIFU exposure possible, a method to reduce the interference of HIFU was developed[1)]. In this study, it was combined with an imaging method called triplet pulse sequence[2,3)] (3P) by which bubbles can be selectively imaged, in order to obtain a bubble image with a high contrast ratio with normal tissue during the HIFU exposure.

2. Materials and Methods

2.1 Experimental setup

Fig. 1 shows a schematic of the experimental setup. Experiments were performed in a water tank with a 128-ch 2D-array transducer at the center of the side wall. A sector probe for ultrasound imaging was mounted in the central hole of the transducer. The focus of the HIFU was located at a depth of 70 mm in the imaging plane. The tank was filled with degassed water (dissolved oxygen saturation of 25% at room temperature). A chicken breast as a sample tissue was set and exposed to HIFU at 1.0 MHz. The center frequency of the transmitted waves for imaging was 1.74 MHz. The HIFU driving and ultrasound imaging systems were synchronized by a function generator.

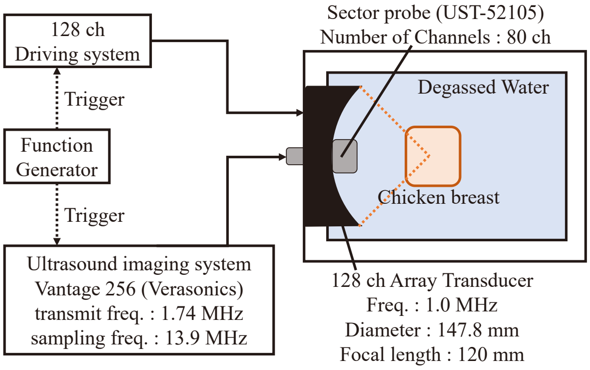

Fig. 1 Schematic of experimental setup

2.2 HIFU exposure and RF data acquisition

Fig. 2 shows the sequence of the HIFU exposure and RF data acquisition. The HIFU sequence repeated for 3 cycles consisted of short pulses called “trigger pulses” to generate cavitation bubbles and bursts called “heating bursts” to oscillate the bubbles and heat tissue. The intensity of the trigger pulse was 130 kW/cm^2. Those of the heating burst were 4200 and 500 W/cm^2.

RF signals were acquired within the interval time between a trigger pulse and heating burst referred as frame-1 and frame-5 in Fig. 2 and during heating burst exposure as from frame-2 to frame-4. Frame-1 and frame-5 consist of 3 diverging-wave transmissions with phase shifts by 120, 0 and 240° which are referred to as F, S and T waves, respectively. In the frames during the HIFU exposure, the RF signals were acquired in a sequential order of F, passive receiving (Pr), S, Pr, and T. The sequence of the acquisition of the RF signals was also repeated for 1 and 2 cycles before and after the HIFU exposure, respectively, in addition to the imaging during the HIFU exposure.

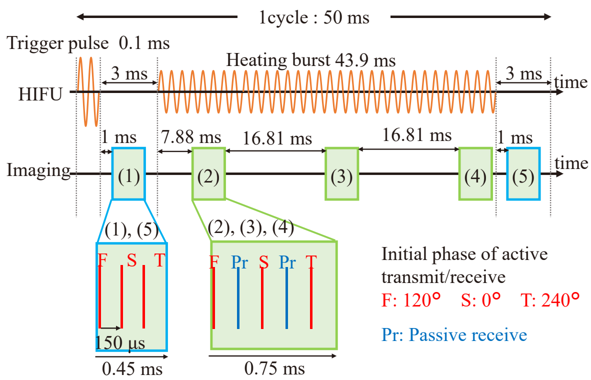

Fig. 2 Sequence of HIFU and ultrasound imaging

2.3 Data processing

The ultrasound images were constructed from the RF signals. The single pulse (1P) and 3P images were constructed by echo from S wave and by summing echo from F, S, and T wave, respectively. In frame-2 to frame-4, the HIFU noise was reduced by subtracting the passive images from the active images. The average of both Pr signals was used to the HIFU noise reduction method.

3. Results and Discussion

Figures 3 (a)-(c) show the B-mode images of 1P at a heating burst intensity of 4200 W/cm^2. Before the HIFU noise reduction, the entire region cannot be observed because of the ultrasonic interference. After the processing, the HIFU noise reduced. However, noise components remained around the cavitation area more than those in other areas. This is attributed to the temporal change in scattering of the cavitation bubbles. Figures 3 (d)-(f) show the B-mode images of 3P at a heating burst intensity of 4200 W/cm^2. The residual HIFU noise was more dominant around the cavitation area in 3P than 1P image. It is reasonable because the echo signal intensity by 3P method is usually much less than that by 1P method while the difference of the residual HIFU noise intensity is not so large. From above, the monitoring of the treatment region (as Region A in Fig. 4) during the HIFU exposure should be performed in the HIFU intermission as in Fig. 3 (c) and (f). It is desirable to monitor bubbles by 3P because the contrast of those to the tissue was higher than that by 1P by 4.2 dB. The normal tissue around the HIFU focus is need to be monitored as well as cavitation. The 3P image superimposed on the 1P image will be a solution for this.

Figures 3 (g)-(i) show the B-mode images of 3P at heating burst intensity of 500 W/cm^2. This intensity of heating burst was tested for the situation that bubbles are unexpectedly occurred outside the treatment region as shown at the top of Region B in Fig. 4, where the HIFU intensity is much lower than that in the focal region. The imaging as in Fig. 3 (h) may be useful to detect such cavitation bubbles. If cavitation bubbles are detected in such a region, it is necessary to stop the HIFU exposure immediately, regardless of the axial position of the bubbles, hence the axial resolution in the bubble detection is not needed to be as high as the monitoring around the treatment region. To monitor the normal tissue in Region B, the image with the HIFU noise reduction by 1P method should be used because the scattered ultrasound from the bubbles in Region A interferes. Therefore, it is desirable for the monitoring in

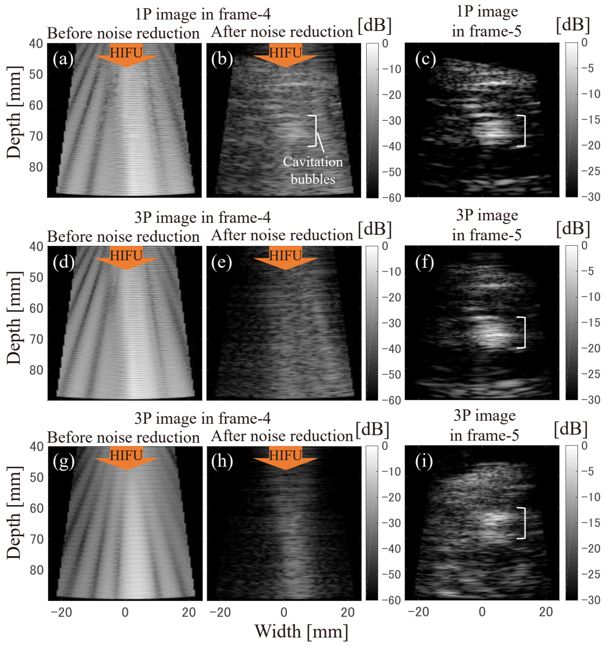

Fig. 3 B-mode images of the 4th cycle at heating burst intensity of 4200 ((a)-(f)) and 500 W/cm^2((g)-(i)).

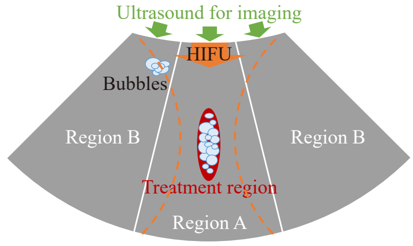

Fig. 4 Interpretation of the treatment monitoring

Region B that the 3P images with the HIFU noise reduction are superimposed on the 1P images with the reduction.

4. Conclusion

In this study, the signal processing method which reduces the HIFU noise was combined with the 3P imaging which can selectively detect bubbles. It is suggested that the HIFU noise reduction method is useful to detect the bubbles outside the treatment region combined with 3P method and monitor the normal tissue during the HIFU exposure. The 3P imaging during the HIFU intermission will be suitable for monitoring the bubbles in the treatment region.

References

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