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Selective detection of cavitation bubbles by triplet pulse sequence in high-intensity focused ultrasound treatment
強力集束超音波治療における
３パルス法によるキャビテーション気泡の選択的検出

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1. Introduction

High-intensity focused ultrasound (HIFU) treatment has been a subject of much interest as a less invasive therapeutic modality for cancer. However, the smallness of treatment area by single HIFU exposure is one of the problems to overcome for the development.

Acoustic cavitation bubbles are known to enhance the thermal effect of ultrasound.[1)] Utilizing cavitation has a potential to improve the efficiency of the treatment, but there are also concerns of damaging normal tissues and shielding the ultrasonic propagation by the microbubbles. Therefore, monitoring of bubble generation is important for the cavitation-enhanced ultrasonic heating to ensure both its safety and efficiency.

To monitor microbubbles with nonlinear ocsilation, the pulse inversion (PI) method,[2)] one of the harmanic imaging techniques, is widely used. However, it is difficult to separate the nonlinear response from microbubbles and the even harmonic components due to nonlinear propagation by extracting the second harmonics using the PI method. In this study, we investigated selective detection of cavitation bubbles by using the triplet pulse sequence,[3)] which is expected to be superior in detecting echoes from microbubbles contrast agents specifically.

2. Materials and Methods

2.1 Triplet pulse sequence

In a PI sequence, two pulses with a phase shift by 180° are transmitted and received, whereas three pulses with the same envelope and a phase shift by 120° are used in a triplet pulse sequence as shown in **Fig. 1**. Microbubble/tissue contrast is expected to be improved because not only fundamental components but also second harmonic components are canceled from the summed echo signals and strong nonlinear scattering from resonant microbubbles, for example 1.5 sub-harmonics, is selectively depicted.

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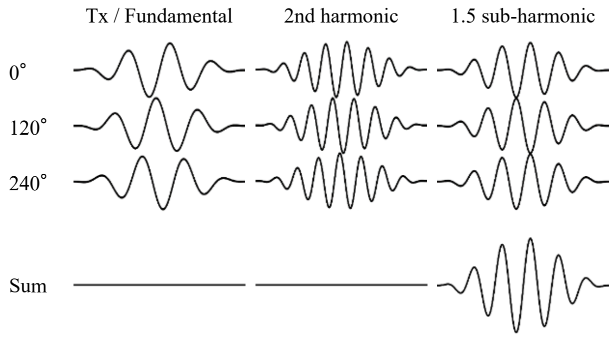

Fig. 1 Principle of triplet pulse sequence

2.2 Experimental procedure

A chicken breast was selected for a sample tissue and placed in a water tank containing degassed water at 37°C. **Fig. 2** shows the sequence of the experiments. Trigger HIFU[1)] was transmitted from a 256-channel 2D-array transducer (Imasonic) with both focal length and diameter of 120 mm, driven by a staircase driving system (Microsonic) at a frequency of 1.25 MHz. High-intensity short pulse called “trigger pulse” at an intensity of 60 kW/cm^2 with a duration of 0.1 ms for generating cavitation bubble clouds around focal zone and following “heating burst” at an intensity of 2.0 kW/cm^2 with a duration of 44.9 ms for oscillating the bubbles to convert ultrasonic energy into heat were irradiated. This sequence was repeated for 160 cycles with a PRF of 20 Hz, resulting total exposure time of 8 s, to induce tissue coagulation.

RF data acquisition was performed during the interval period of 5 ms via a sector probe (Hitachi Aloka Medical UST-52105), set in the central hole of the transducer, connected to an ultrasonic imaging system (Verasonics The Vantage 256) at a sampling frequency of 14 MHz. Diverging wave pulses at a center frequency of 1.74 MHz with a prospective angle of 6°, steering angles of -6, -3, 0, 3 and 6° and initial phases of 0, 120 and 240° at an imaging PRF of 5 kHz were transmitted. The total of 15 data by delay-and-sum receive beamforming were coherently compounded to construct a frame.

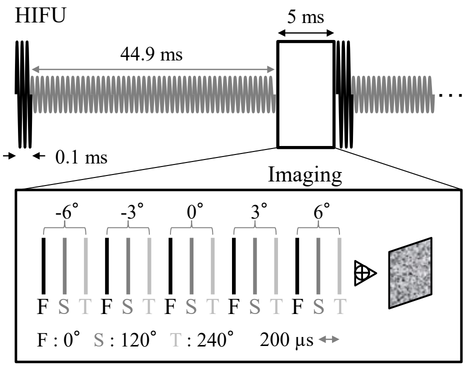

Fig. 2 HIFU and imaging sequence

3. Results and Discussion

Fig. 3 shows the transmit waveforms and their spectra used in the PI and triplet pulse sequences, respectively, which were acquired by a hydrophone (Onda HGL-0085). The fundamental components (around 1.74 MHz) and the second harmonics (around 3.47 MHz) were canceled from the summed signal by the triplet pulse sequence and the third harmonics (around 5.22 MHz) and 0.5 sub-harmonics (around 0.87 MHz) were enhanced in comparison with that by the PI sequence.

Fig. 4 shows the B-mode images 2 s after the start of the HIFU exposure acquired in each imaging sequence. "Single pulse" denotes the image acquired by using only pulses with an initial phase of 0°. The linear components from tissues were suppressed in both the PI and the triplet pulse sequence. The cavitation bubbles seem to be better depicted by the triplet pulse than PI sequence.

Fig. 5 shows the spectra of RF data averaged over all acquired frames. The fundamental components were canceled from also the summed echo signals in both the PI and triplet pulse sequence. A significant difference appeared in the second harmonics, which were canceled only in the triplet pulse sequence. Since the spectra are derived from the whole data constructing a frame, the components originated from the localized microbubbles are not well enhanced, however, the expected performance were confirmed.

4. Conclusion

In this study, a triplet pulse sequence, which is one of the harmonic imaging method with no band limitation by a filter, was proposed to apply detecting cavitation bubbles selectively. The sequence canceled out the second harmonics as well as the fundamental components. The results suggest the potential to image cavitation bubbles specifically by separating the nonlinear response from microbubbles from the even harmonic components due to nonlinear ultrasonic propagation.

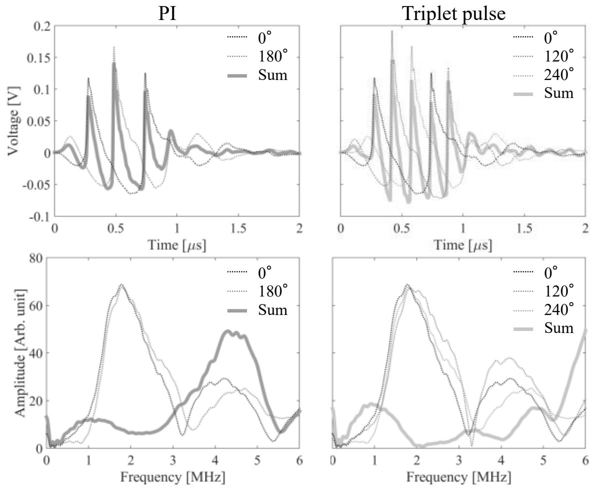

Fig. 3 Transmit waveforms and their spectra

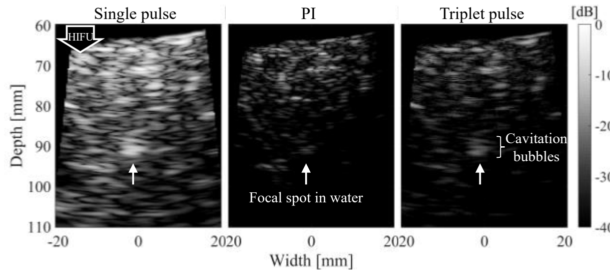

Fig. 4 B-mode images during HIFU exposure

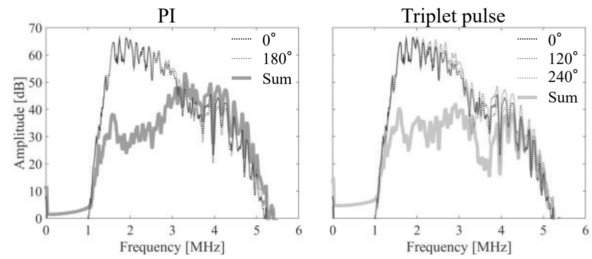

Fig. 5 Spectra of echo signals

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