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Monitoring of High-Intensity Focused Ultrasound Treatment Using Shear Wave Elastography Induced by 2D Array Therapeutic Transducer
治療用トランスデューサ加振による剪断波エラストグラフィを用いた治療モニタリング

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1. Introduction

High-Intensity Focused Ultrasound (HIFU) is a less invasive treatment method, in which ultrasound is gererated outside the body and focused at a target tissue such as tumor to be thermally coagulated. In HIFU treatment, the long treatment time due to the smallness of the tissue volume coagulated by a single irradiation and the invisibility of the treatment by the naked eye are the problems to overcome. Therefore, a noninvasive monitoring method compatible with an efficient coagulation method is desired. To achive this purpose, we have proposed a method using acoustic cavitation bubbles to accelarate the treatment[1)] by enhancing the heating effect of ultrasound and applying Shear Wave Elastography (SWE)[2)] to detect the coagurated region[3)].

In a conventional SWE technique, in which push beams are insonated by an imaging probe, it is challenging to induce adequate axial displacements of shear waves in deep tissue. In this study, to achieve the same penetration of shear waves as the tissue coagulation induced by HIFU, we propose using a 2D array therapeutic transducer for not only inducing thermal coagulation but also creating shear sources in the tissue.

2. Materials and Methods

2.1 Experimental setup and sequence

Experiments were performed in a water tank, containing degassed water and equipped with a therapeutic transducer as shown in **Fig. 1**. A chicken breast soaked with degassed saline was used as a sample tissue.

The overall ultrasound exposure sequence is shown in **Fig. 2**, in which the upper half part shows the sequence of therapeutic ultrasound exposure from a 256-channel 2D array transducer (Imasonic) at focal length of 120 mm at a driving frequency of

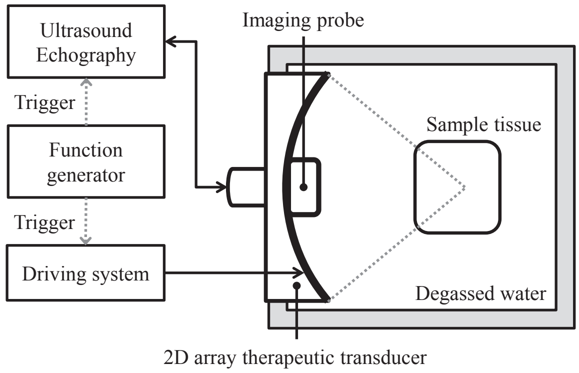

Fig. 1 Schematic of experimental setup

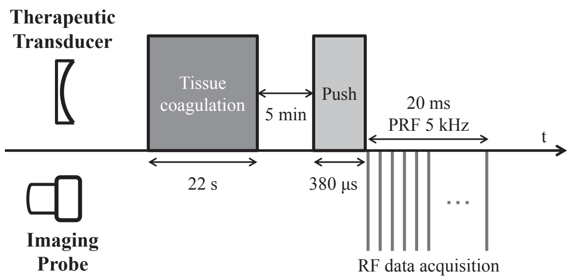

Fig. 2 Sequence of ultrasound transmission

1.0 MHz and the lower half part shows the sequence of diagnostic ultrasound exposure from a sector probe (Hitachi Aloka Medical UST-52105) with a transmit frequency of 3.47 MHz, set in the central hole of the therapeutic transducer.

2.2 HIFU sequence

In order to efficiently induce tissue coagulation, a "multiply triggered HIFU" sequence[4)] was used, in which the focus was laterally scanned at each corner of a regular hexagon 3 mm each side. "Trigger pulses" at an intensity of 64 kW/cm^2 with a duration of 25 μs for 4 cycles to generate cavitation bubble clouds were followed by "Heating waves" at an intensity of 2.2 kW/cm^2 with a duration of 25 μs for 834 cycles to oscillate the cavitation bubbles. This sequence was repeated 160

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times, resulting in a total HIFU exposure duration of about 22 s, which was long enough to coagulate the tissue.

2.3 SWE sequence

In the SWE sequence in this study, push beams were irradiated by the HIFU transducer at seven different depths (111, 114, 117, 120, 123, 126, and 129 mm) and an intensity of 9 kW/cm^2 with a duration of 50 μs at each spot and an interval of 5 μs, resulting in a total push beam duration of 380 μs. After creating shear sources, the transmission of plane wave imaging pulses followed by reception was repeated with a PRF of 5 kHz using the imaging probe connected to an ultrasonic imaging system (Verasonics Vantage) to track shear waves propagation. The axial displacements were calculated by the phase shift of the 1D cross-correlation between obtained adjacent RF frames. The shear wave propagation velocity at each point was estimated via a time-of-flight algorithm applying a least-squares method. Since the shear modulus highly depends on the temperature, a cooling time of more than 5 min was provided after the therapeutic sequence before the SWE sequence.

3. Results and Discussion

The measured axial and lateral sizes of the actual coagulated region induced by the multiply triggered HIFU were about 20 mm and 10 mm as shown in **Fig. 3**.

The distributions of the shear wave propagation velocities before and after the therapeutic exposure are shown in **Fig. 4**. Comparing the maps, the increased shear wave velocity region in almost the same size as the actual tissue coagulation was depicted clearly. Since the imaging probe is projected 26 mm from the surface of the 2D array transducer, the geometrical focal point of the HIFU transducer of 120 mm corresponds to the depth of 94 mm in these maps. The shear waves with an enough SNR to estimate propagation velocities had been difficult form at this depth using the imaging probe.

Fig. 5 shows the subtraction B-mode image of before and after the therapeutic exposure, in which the remaining bubbles are depicted as bright pixels. This suggests that SWE works to detect coagulated region even in the presence of microbubbles caused by cavitation or boiling.

4. Conclusion

In this study, it showed that the detection of thermal coagulation by SWE induced by a HIFU transducer is effective to monitor HIFU treatment of deep tissue even in case it was enhanced by acoustic cavitation.

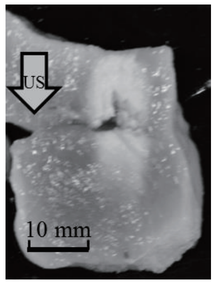

Fig. 3 Slice of sample after HIFU exposure

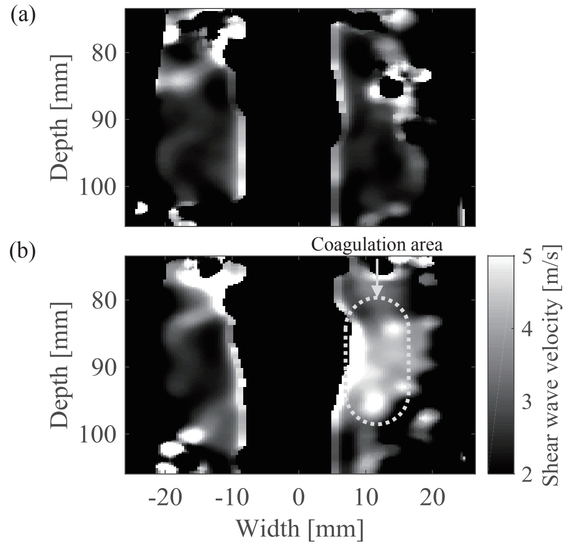

Fig.4 Shear wave velocity maps (a)before (b)after HIFU exposure

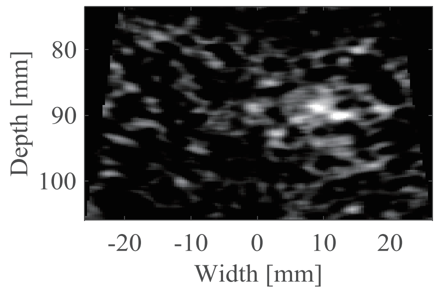

Fig.5 Subtraction B-mode image

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