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Contrast Enhanced HIFU Beam Imaging using Speckle Reduction

スペックル除去による高コントラストな HIFU ビーム可視化技術

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1. Introduction

High Intensity Focused Ultrasound (HIFU) has been considered as a non-invasive or minimally invasive medical procedure for precise tumor ablation such as prostate cancer, liver cancer, breast cancer. The focused acoustic energy in human body is absorbed by tissue and is converted into heat in order to ablate tumors. We developed a HIFU beam imaging (HBI) method to monitor HIFU beams in real time during the HIFU exposure [1]. In HBI reported in our previous research, transmitted pulse length was set as 2-cycle. However, HIFU treatment is conducted by continuous wave of HIFU beam, which has different acoustic field of burst wave of HIFU beam. In this study, we controlled the pulse length of HIFU beam in HBI to visualize transmitted HIFU beam in tissue.

2. Methods

In HBI, an imaging pulse of HIFU beam is transmitted from a HIFU transducer, and a receiving beam of an imaging probe was scanned simultaneously in its imaging area, while the transmitting beam was not scanned. Using HBI, spatial distribution of HIFU beam is reflected by an echo distribution acquired by the receiving beam. In this study, pulse-cycle of the HIFU beam was controlled to optimize the beam profile of HBI obtained by echo signal. We evaluated the obtained beam profile by comparing simulated transmission of HIFU beam.

3. Experimental Setup

As shown in Fig. 1, a diagnostic ultrasound probe was inserted in the HIFU transducer, which consisted of 256 elements (Imasonic, France). It had a central frequency of 2MHz, a focal length of 100mm, and an f-number of 0.8. To put an imaging array coaxially in the HIFU transducer, it was made of a hollow structure of 40mm diameter. A small prototype linear array probe, composed of 128 elements with a 6.5 MHz central frequency and a 0.2mm pitch, was used to perform ultrasonic imaging.

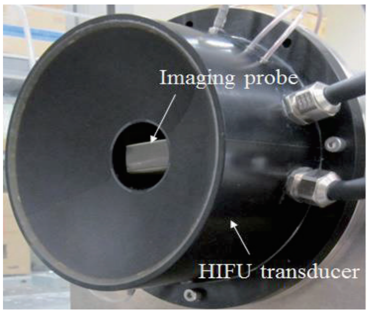

Fig. 1 Configuration of a HIFU transducer and an imaging probe.

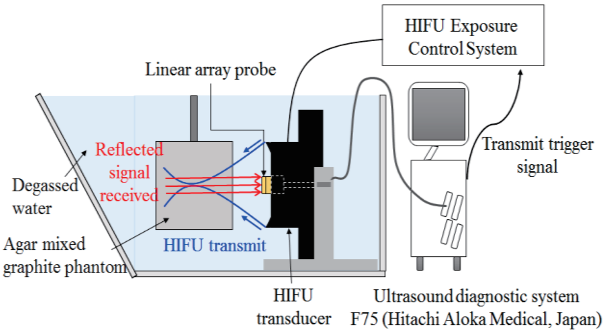

Fig. 2 Experimental setup of HIFU Beam Imaging.

The experimental setup of the HBI system is shown in Fig. 2. An ultrasound diagnostic system (modified F75, Hitachi Aloka Medical, Japan) was used. Synchronizing with the trigger signal of the diagnostic system, the HIFU beam and each of the scanning beam lines were transmitted simultaneously. 2MHz k-cycle ($k = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20$) burst waves were transmitted from the HIFU transducer. The linear array probe formed 150 scanning beam lines with a pitch of 0.15mm. A beam line showing a signal in the focus area was

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selected. A band-pass filter was applied to detect the 2nd harmonic wave of the echo signal. The band-pass filter's center frequency was 4MHz, and the -6dB width was 1.4MHz. A homogeneous 3% agar phantom mixed with 2% powdery graphite was used as the target.

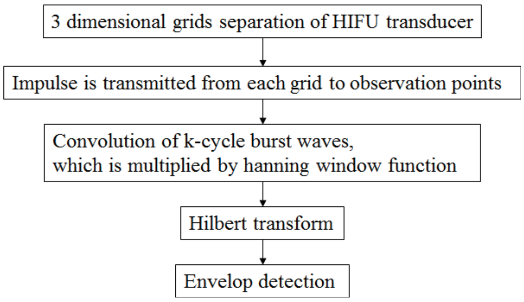

Fig. 3 Simulation steps of transmitted HIFU beam.

Fig. 3 shows the simulation steps for calculating the transmitted HIFU acoustic field. In this simulation, the HIFU transducer is separated by grids, which were arranged in wavelength intervals. The acoustic velocity was set at 1530m/s.

4. Results and Discussions

Fig. 4 displays the beam profile of the HIFU in experiment (red) and simulation (blue). The simulation results indicated that the beam width (BW) widens as k increases. The experiment shows a fluctuated HBI beam profile. This fluctuation resulted out of the scattering speckle pattern of the phantom. To evaluate the beam fluctuation (BF) quantitatively, the index of fluctuation per input acoustic energy of HIFU is defined as follows:

$$BF(k) = \int \left| I_{exp}(k,z) - I_{sim}(k,z) \right| dz \Big/ \int I_{sim}(k,z)\, dz$$

where z is the depth direction, range of which is 85 - 115mm; I_{exp} is the experimental data as a target of HBI; I_{sim} is the simulated data of HIFU. Fig. 5 shows the simulated BW and the BF obtained in the experiment. As k is increased, BW got closer to 5mm, which is calculated as the BW of a continuous wave ($k \gg 1$), and BF decreased. On the other hand, as k increased, the pulse length $k \cdot \lambda$ lengthened, leading to a low resolution of HBI.

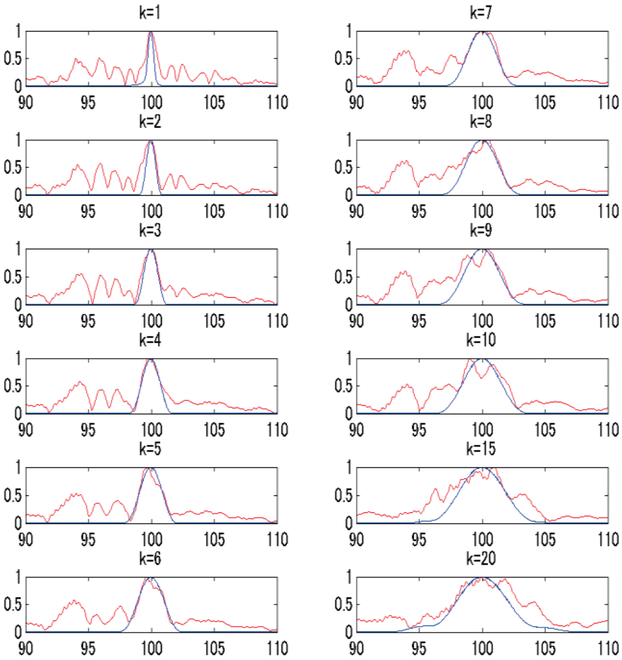

Fig. 4 Beam Profiles by controlling the pulse cycle number k. The horizontal axis shows the depth [mm]. On the vertical axis, the normalized intensity is displayed. Red lines are results, indicating the echo signal of HBI in the experiment. Blue lines are HIFU transmitted beam in the simulation.

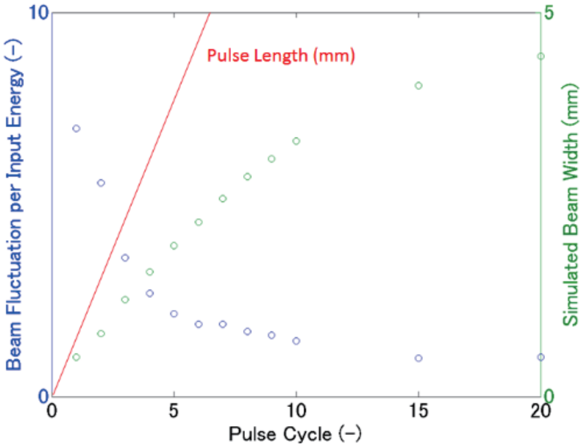

Fig. 5 Beam fluctuation of HBI, simulated beam width, and pulse length.

5. Conclusion

In this study, we controlled the pulse length of the transmission burst wave of HBI to optimize a visualized beam profile of transmitted HIFU beam in the target. Evaluating simulated HIFU beam profile and echo data of HBI in the experiment, we found that more a desirable beam profile could be acquired it the pulse length were increased, even though the resolution of HBI inevitably decreases.

Acknowledgments

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References

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