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Study on Ultrasonic Monitoring Using 1.5 Dimensional Ultrasound Phased Array in US-guided High-Intensity Focused Ultrasound Treatment

1.5D アレイプローブを用いた集束超音波治療モニタリングに関する基礎検討

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1. Introduction

High-Intensity Focused Ultrasound (HIFU) is therapeutic treatment which ablate various tumors non-invasively, such as prostate cancer and uterine fibroids. In our previous study[1], tissue caoagulation was detected by the change of ultrasound RF signals acquired by the 1D imaging probe on the same axis as the HIFU transducer. In this method, it is difficult to track the tissue changes when treated region in the tissue was deviated from the imaging plane in the elevation axis of the probe due to the tissue motion. In this study, the new phased array probe which consists of elements along both lateral and elevation axis was developed to track the tissue motion in the elevation axis of the probe and the elevational displacement range, where the tracking is effective, was investigated.

2. Material and Methods

2.1 Structure of the 1.5D Phased Array Probe

The structure of the phased array probe is schematically shown in **Fig.1**. The probe consists of flat 256 elements made of piezocomposite where 64 and 4 elements are along the lateral and elevation axis, respectively. The consideration behind the design is that tissue motion within a few mm in the elevation direction is to be tracked while keeping practically the same lateral resolution as a 1D conventional phased array probe during HIFU exposure, which has been proven to be effective to detect HIFU induced tissue coagulation in our previous studies. The lateral width and the pitch of the elements in lateral and the elevation height are 0.2, 0.3 and 0.3 mm, respectively. The center frequency of the probe was 3 MHz.

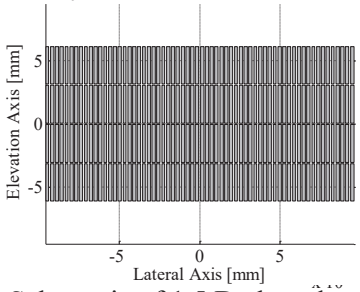

Fig.1 Schematic of 1.5 D phased array probe

2.2 Experimental Setup

The 1D beam profile in the lateral and elevation axis with and without focusing was measured to investigate the feasibility of the suggested phased array probe and compared with the simulation results. A linear transient simulation using Fast Object-Oriented C++ Ultrasound Simulator (FOCUS) was used as a simulation tool to calculate the pressure field.

A schematic of the experimental setup to investigate the elevational displacement range to track the tissue motion is shown in **Fig. 2**. The chicken breast tissue was used as a specimen and placed on a holder in degassed water. 1.5D phased array probe was mounted above the specimen and ultrasound RF signals were acquired while the array probe was moved along the elevation axis at a pitch of 0.5 mm. A programmable ultrasound imaging system (VerasonicsV-1 System) was used to acquire the RF signals. 2.5D volumetric RF images were produced by applying the plane wave transmission. Apodization was applied to the elements along the elevation axis in receiving through the beamforming process to reduce the side robe artifacts. The complex cross-correlation coefficient based on a block matching algorithm was calculated between lateral RF image blocks shifted also in the elevation axis to track 3D tissue motion. The displacement vector was also calculated by searching the maximum correlation coefficient between the RF image blocks.

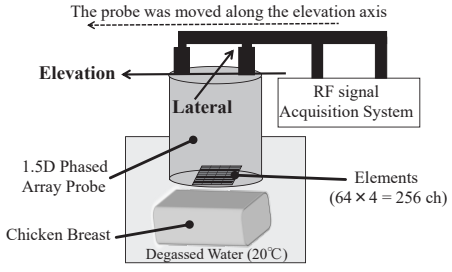

Fig.2 Schematic of experimental setup

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3. Results and Discussion

Figures 3 (a) (b) shows simulated versus measured lateral and elevation beam profiles without focusing (plane wave transmission) and with focusing at 50 mm in depth at 3MHz. The simulation results matched the measured results well, demonstrating that the pressure field was produced correctly by the prototype 1.5D phased array probe. As shown in **Fig. 3** (c) (d), the -6 dB lateral and elevational focal widths are about 1.6 and 3.2 mm respectively.

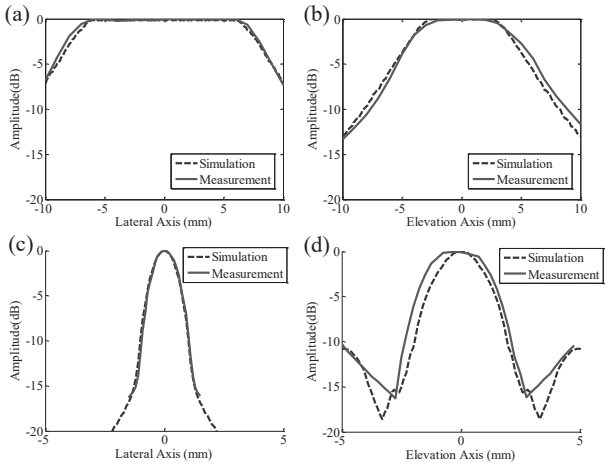

Fig.3 Simulated (solid line) and measured (dashed line) lateral and elevation beam profile without focusing ((a), (b)) and with focusing at 50 mm in depth ((c), (d)).

Figure 4 shows the comparison between simulated 1D beam profiles along the elevation axis when focusing at 50 mm in depth with and without applying the apodization to the elements along the elevation axis. As shown in **Fig.4**, the side robe level is reduced by about 4dB by applying the apodization. The expected reduction of the side robe artifacts can significantly improve the tracking capability of the elevational displacement of the tissue.

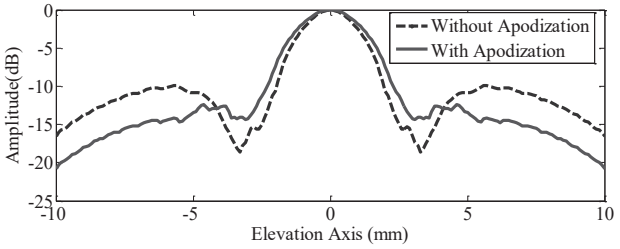

Fig.4 Comparison between simulated 1D beam profiles along the elevation axis when focusing at 50 mm in depth with and without applying the apodization to the elements along the elevation axis.

Figure 5 compares of the correlation coefficients between the RF images without or with tracking the elevational tissue motion plotted against the elevational shift of the tissue. As shown in **Fig.5**, the correlation coefficients keeps around 0.8 and the tissue motion was successfully tracked when the tissue moved up to about 3 mm along the elevation axis. Without tissue tracking (1D imaging) in contrast, the correlation coefficients decreased drastically when the tissue moved more than 1 mm along the elevation axis. These results imply that tissue coagulation can be detected using the prototype probe when the tissue moves up to about 3 mm along the elevation axis during HIFU exposure. The conventional ultrasonic monitoring rate of HIFU treatment is about 10 to 20 Hz. Therefore, it is assumed that the tissue coagulation can be detected using the prototype probe when the tissue is moving in elevation axis at a speed of 3 to 6 cm/s.

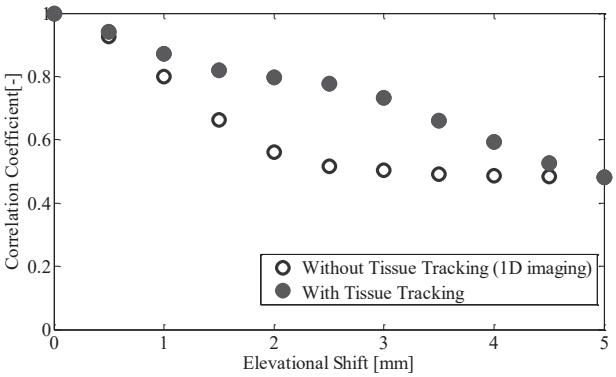

Fig.5 Comparison of correlation coefficient between the RF images and elevational shift of the tissue using the block matching algorithm.

4. Conclusion

In this study, the new 1.5D phased array probe consisting of elements along both lateral and elevation axes was developed to detect the tissue coagulation induced by HIFU when the tissue motion along the elevation axis cannot be ignored. The results imply that the elevational displacement range to track the tissue motion was improved about 3 times compared with the conventional 1D imaging. The proposed 1.5D phased array probe has a potential to detect the tissue coagulaton induced by HIFU in more practical situation with intrafractional motion of the tumors.

References

1. R. Takagi et al: Jpn. J. Appl. Phys. **55** (2015) 07KC10.