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Velocity measurement of shear-wave 2D propagation using high-speed Localized Motion Imaging

高速 LMI を用いたずり弾性波の二次元伝播速度計測

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1. Introduction

High Intensity Focued Ultrasound (HIFU) has been interested as a minimally invasive treatment for cancerous tumors. In this treatment, the high energy acoustic beam can create irreversible thermal coagulation at the focus of the transducer. The HIFU can be used as a local treatment method within the focal area without irreversible thermal damage to the surrounding normal tissue. However, living tissues have acoustic inhomogeneity; therefore, it is necessary to develop a monitoring system for control of thermal coagulation

Ultrasound (US) imaging has been studied as a non-invasive HIFU monitoring system, because it can provide portability, low cost and spatiotemporal resolution. However, the longitudinal sound velocity that is one of an acoustic property changes only a few percent before and after thermal coagulation. Hence, it is difficult to detect the coagulation area from a B-mode image. In contrast, the stifness of living tissue change drastically. In a typical experiment with liver tissue, the shear modulus after coagulation was approximately 10 times larger than that before coagulation[1]. US coagulation imaging system for monitoring based on change of tissue mechanical properties have been reported.

In this paper, the development of a 2D dimentional coagulation mapping method was described.

2. Methods

2.1 Localized Motion Imaging

Localized Motion Imaging (LMI) was one of the techniques to detect a change of tissue stiffness caused by its thermal coagulation for HIFU treatment[2]. In this method, acoustic radiation force generated by HIFU was used as a mechanical input to deform tissue at the focus, and the tissue displacement was in the order of ten µm. The acoustic radiation force was modulated by changing the amplitude of US intensity. The size of local vibrated area could be controlled by amplitude modulation (AM) frequency. The tissue deformation was measured by pulse-echo method using an imaging probe placed at the center of the HIFU transducer. The tissue displacement was estimated by cross-correlation between consecutive frame echo signals[3]. The local vibration by AM frequency HIFU beam was propagated as shear wave. Shear wave velocity increased drastically after coagulation because the velocity was proportional to the square root of the shear modulus. Hence, the coagulation area was estimated by the increase of shear wave velocity. In previous study, 1D estimation of coagulated area was constructed using the change of shear wave velocity in vertical direction. Meanwhile, shear wave velocity in lateral direction was not measured. Since mechanism of lateral propagation is relatively easy to understand rather than that of vertical propagation, the comparion of both propagtions in different directions was expected to contain informative results. Therefore, velocity measurement of shear wave 2D propagation using LMI is studied in this research.

2.2 PZFlex simulation

PZFlex can be used as a simulator of ultrasound propagation, generation of an acoustic radiation force and shear wave propagation in a tissue. In the simulation condition, AM frequency, the speed of shear wave, the focal distance of HIFU, the grid size and time resolution were 200Hz, 1.0 m/s, 20 mm, 80 µm, and 0.85 µs, respectively. A coagulated region size was 8 and 4 mm in vertical and lateral, respectively. The shear modulus of coagulated region was ten times as large as that of soft tissue.

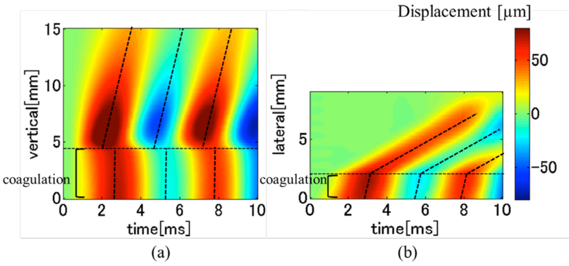

Fig. 1 PZFlex shear wave simulation

Fig. 1 shows images of the elastic displacement.

They show the shear wave from the focus in vertical (a) and in lateral (b). Shear wave velocity in the soft tissue is 4.0 m/s in vertical and 0.95 m/s in lateral. The shear wave propagation changes in the coagulated region and a soft tissue. In addition, a phase gap generates the shear wave in vertical direction.

2.3 Experiment

Experimental setup and our prototype monitoring system using LMI are shown in **Fig. 2**. 48-frames RF data obtained by an imaging probe were acquired by Verasonics PC in every 1 second.

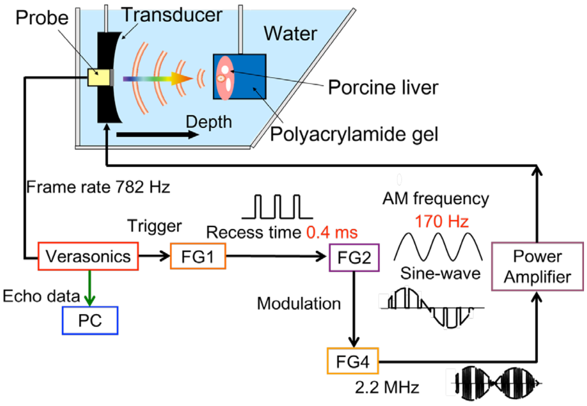

Fig. 2 Experimental setup

Sampling rate was 782 Hz and the imaging beam was transmitted and received in HIFU recess time. The imaging beam irradiated from the probe was parallel beam that scans 2D domain in the focus. The sampling frequency was 20 MHz and the lateral grid was 0.20 mm. The target porcine liver tissue was embedded in polyacrylamide gel. **Fig. 3** shows a B-mode image of liver tissue. The distance between the surface of tissue and the focus was 10 mm. In this experiment, AM frequency was 170 Hz. HIFU frequency and intensity were 2.2 MHz, 2.0 kW/cm^2, respectively. The focal distance of HIFU beam is 65mm, and the beam width was 7 mm in depth, 0.7 mm in width.

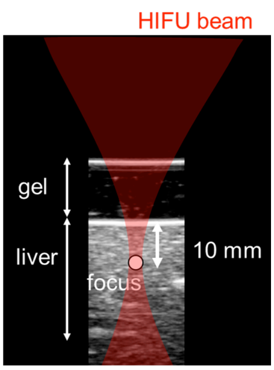

Fig. 3 B-mode image of liver tissue

The experiment was conducted as follows:

1. Tissue was ablated for 20 seconds with acquiring RF data
2. After ablation, the tissue displacement using cross-correlation was estimated
3. The velocity of shear wave 2D propagation was measured from the displacement map

3. Results

Fig. 4 show images of the tissue displacement that is obtained using LMI 10 seconds later. They show the shear wave from the focus in vertical (a) and in lateral (b). The horizontal and vertical axes are frame-axis and vertical distance from tissue surface in (a) and lateral distance from focus in (b). Shear wave velocity in the tissue was 1.5 m/s in vertical and 0.73 m/s in lateral.

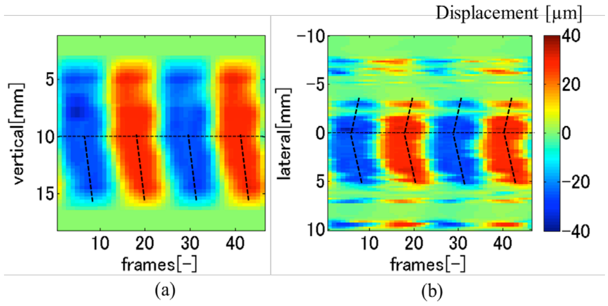

Fig. 4 displacement map using LMI

In vertical direction, shear wave propagated from the focus asymmetrically. Vibration to produce by an acoustic radiation force by the HIFU beam than a shear wave to spread from the focus was more dominant in the tissue just before the focus. In lateral direction, shear wave propagated from the focus symmetrically. However, detected propagation distance from the focus was too short to estimate shear velocity in the surrounding tissue. It is suggested that the attenuation of the shear wave in living tissue is too high in the current system with the parallel beam LMI method.

4. Summary

The system of measuring shear wave 2D propagation based on LMI monitoring has been constructed, and HIFU ablation experiments were conducted. In the proposed method, 2D shear wave propagation was detected around the HIFU focus.

References

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