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In vivo Estimation of Sound Velocity Distribution for Diagnosis of Chronic Liver Disease and High Resolution Ultrasonic Tomographic Imaging

慢性肝疾患の診断と超音波断層像の高分解能化を目指した生体内音速分布推定

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1. Introduction

Medical ultrasound imaging has high performance in depicting soft tissue, and it can be repeated because of its safety. Therefore, it is very useful in the diagnosis of various diseases and observation of various organs. However, there is a problem that the image quality in ultrasonic tomographic imaging deteriorates due to the heterogeneity of sound velocity in *in vivo* tissue. It is also known that the sound velocities change in the living body, particularly in the livers, due to fatty metamorphosis or the growth of fibrous tissues. Based on these backgrounds, it is possible to improve the image quality in ultrasonic tomographic imaging and to diagnose chronic liver disease by estimating the sound velocity distribution in the liver. We have developed a method to estimate the sound velocity distribution using an ultrasonic propagation time from the scatterer to each element of the ultrasonic probe[1)]. In the present paper, we applied this method to the human liver and evaluated its effectiveness through the basic experiment.

2. Materials and Methods

Estimation method of sound velocities

Reflected waves from point scatterers existing in the measurement area were received by an ultrasonic probe. The ultrasonic propagation time from the scatterer to each element of the ultrasonic probe was measured. The sound velocity distribution can be estimated[1)] by comparing the measured propagation times and a theoretical parabolic equation including unknown coefficients, viz., sound velocity and propagation length, in each area of the distribution.

3. Experiment and Result

3.1 *In vivo* Experiment and Result

First, we applied this method to living body to confirm the usefulness of this method. In previous reports, usefulness of this method has been confirmed when the target is a high-intensity point scatterer[1)]. We examined human liver as the target subject because it is known that high-intensity scatterers such as small blood vessels exist in the liver[2)]. A subject is 24-year-old healthy male. We used an ultrasonic diagnosis equipment (Prosound α10, Hitachi Aloka) with liner probe UST-5412. The transmitting frequency was set at 10 MHz. 96 elements were used for transmitting and receiving ultrasonic beams. **Figure 1** shows the measured ultrasonic tomogram. We confirmed the presence of high-intensity scatterer in the liver.

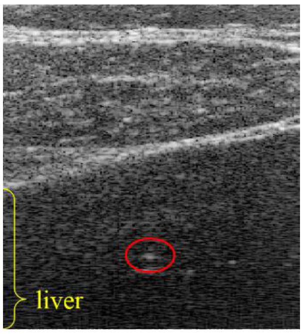

Fig. 1. Ultrasonic tomogram of human liver. (Micro blood vessels in the red ellipse)

Figure 2(a) shows the calculation result of the cross-correlation for the received RF signals obtained by reflection from this scatterer. Figure 2(b) shows the distribution of the ultrasonic propagation times calculated using the cross-correlated result and the approximated curve by the least squares method.

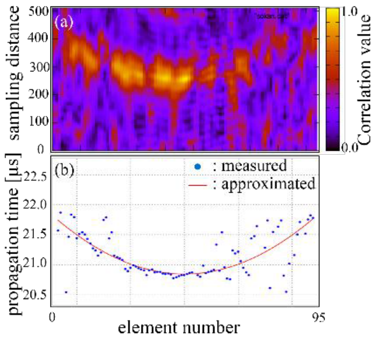

Fig. 2. (a) Correlation value, (b) Propagation time.

The average sound velocity from the probe to the target small blood vessels in the liver was estimated to be about 1,530 m/s. This result indicated the effectiveness of the method of estimating sound velocity distribution in *in vivo* liver. However, the validity of the estimate velocity is unknown. In the proposed estimation method, scatterers were considered as points. Since a blood vessel has a size, it is necessary to consider the influence of the size (diameter) of the point scatterer on the sound velocity estimation. Therefore, we examined the relationship between the size of the object and the estimation accuracy.

3.2 Basic experiment and Result

We confirmed the estimation accuracy of our proposed method by basic experiment using the target objects with different sizes. As the target objects, Nylon wires with diameters of 0.25 mm, 0.5 mm, 0.75 mm and 0.90 mm were used. Each wire was set at the depth of 30 mm from the probe in water. The sound velocity in water was 1495 m/s. **Figure 3** shows the ultrasonic images of nylon wire ((a) diameter 0.90 mm, (c) diameter 0.25 mm) and the received waveforms at the center element of the probe. From Fig. 3, the separation of reflected waves from the front and rear walls were observed.

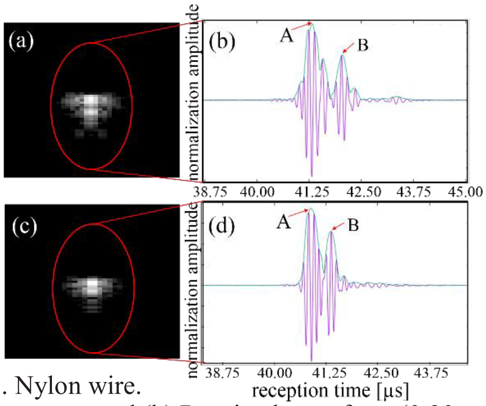

Fig. 3. Nylon wire.
(a) Tomogram and (b) Received waveform (0.90 mm),
(c) Tomogram and (d) Received waveform (0.25 mm).

The measurement for each wire was repeated five times, and the average sound velocities and the depths of the wires were estimated. The wire was rearranged in each measurement. The estimated sound velocities were compared with the true velocity in **Fig. 4**. From this result, it was confirmed that the estimated sound velocity was close to the true value regardless of the diameter of the scatterers, although the result in the scatterer diameter of 0.25 mm had bias error of approximately 10 m/s. As the diameter of the scatterer increased, the variance of the estimated velocity increased.

To consider the cause of the variations, the received waveforms were compared in the same time scale (Fig. 3(b) and (d)) for the scatterers with diameters of 0.90 and 0.25 mm. The time differences between A and B in Fig. 3 were 0.73 µs in (b) and 0.50 µs in (d), which is different from the expected ratio of time difference which should be equal to diameter ratio of scatterers. This reason was that the time at which the amplitude of the reflected wave from the rear wall becomes maximum was changed by the interference of two reflected waves because two reflected waves were not completely separated in the time domain. In this measurement, two reflected waves were included in the correlation window with a width of approximately 2.5 µs for calculating the delay time. Since the propagation path length from the front wall and that from the rear wall differ depending on the position of receiving element, there is a possibility that this interference affects the decrease in accuracy of the sound velocity estimation.

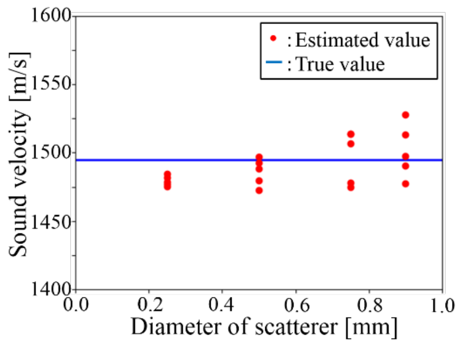

Fig. 4. Sound velocities estimated for different diameter of scatterers.

We investigated several small blood vessels in the liver. In some cases, two reflected waves were observed similar to the waves in Fig. 3(b) and (d) (around 41.25 µs in **Fig. 5(b)**). Therefore, it is necessary to investigate the influence of the interference of reflected waves from the front and rear walls on the sound velocity estimation and to develop a method to improve the estimation accuracy.

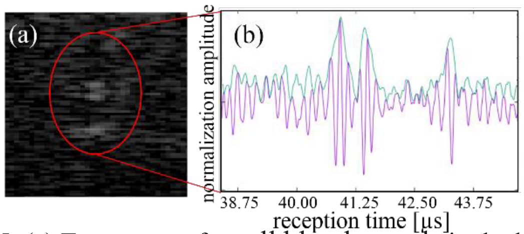

Fig. 5. (a) Tomogram of small blood vessels in the liver, (b) Receive waveform (Central element).

4. Conclusion

In the present study, we investigated the possibility of applying the sound velocity distribution estimation method to the living body and indicated the effectiveness of the proposed method. We discussed the influence of the difference in diameter of target scatterers on the sound velocity estimation through the basic experiment using nylon wires set in water. In this experiment, it was suggested that the reflected waves from the front and rear walls interfere, and the estimation accuracy may decrease. We will investigate the influence furthermore and develop the method to improve the estimation accuracy.

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References
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