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Ex vivo evaluation on the accuracy of modified average sound speed estimation

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1. Introduction

The speed of sound (SoS), which is the propagation speed of longitudinal wave, is expected to be effective for early detection and monitoring of diseases, and several methods using a handheld probe have been proposed. The focusing method based on the time delay correction of the wavefront from a strong scatterer is the simplest method for estimating the average sound speed in the homogeneous tissue. Therefore, we have evaluated the focusing method by conducting numerical simulations and phantom experiments so far.[1)] In addition, we have modified the focusing method to reduce the fluctuations in the estimation accuracy that depend on the position of strong scatterer, and evaluated the modified average sound speed estimation (that is, the improved focusing method) by conducting phantom experiments.[2)] However, in the previous studies, only experiments using phantoms have been conducted, and the applicability to actual tissues has not been verified. In this study, we investigated the applicability and accuracy of the improved focusing method for the excised chicken liver.

2. Modified Average Sound Speed Estimation

In the improved focusing method, the following improvement was made to reduce the measurement error due to the horizontal misalignment of the positions of the central element on the linear array probe and the strong scatterer in tissues.[2)] Assuming that the horizontal positions of the strong scatterer and the central element on the linear array probe do not match each other, a variable x_0 representing the magnitude of this misalignment is newly added, and the time delay corrections of channel data are conducted based on the following equation.

$$\tau_i(x_0, c_{TEST}) = \frac{t_0}{2}\left\{\sqrt{1+4\left(\frac{i\Delta x - x_0}{c_{TEST}t_0}\right)^2}-1\right\}, \quad (1)$$

where t_0 is the appearance time of the echo from the strong scatterer received at the central element, i is the channel number, Δx is the element pitch, c_{TEST} is the test value of the average sound speed estimation, and τ_i is the time delay of i-th channel on the linear array probe. Next, as shown in Eq. (2), the envelope of the aperture synthetic wave of the channel data s_i corrected by τ_i is calculated. In the time range $T_1 \le t \le T_2$, which includes the appearance time of the echo from the strong scatterer, (t, x_0, c_{TEST}) that yields the maximum amplitude of the envelope of the aperture synthetic wave is searched. Finally, c_{TEST} is determined as the estimated value c_{EST} of the average sound speed.

$$c_{EST} \leftarrow max\left\{env\left(\sum_{i=1}^{L} s_i\big(t, \tau_i(x_0, c_{TEST})\big)\right)\right\}, \quad (2)$$

where L is the total number of channels and $env(\cdot)$ represents the envelope calculation. The sound speed, c_{EST}, was estimated by varying c_{TEST} from 1300 to 1800 m/s in steps of 1 m/s.

3. Ex Vivo Experiment

Figure 1 shows a setup for the ex vivo experiment. As shown in Fig. 1(a), a chicken liver was embedded in the area indicated by the dashed line inside a homogenous agar phantom, and a wire with a diameter of 0.6 mm was also embedded as a strong scatterer. The phantom embedded with the chicken liver was placed on a 10 mm thick absorber, and a linear array probe (L7-4, Phillips, USA; 5.2 MHz, 128 channels, element pitch: 0.298 mm) was placed on top of the phantom. Here, the linear array probe is in direct contact with the surface of the liver. Figure 1(b) shows the B-mode image of an embedded chicken liver. Channel data were collected using an ultrasound research platform (Vantage 64LE, Verasonics, USA) and sound speed estimation was conducted by using the improved focusing method and collected channel data.

In this ex vivo experiment, to evaluate the accuracy or resolution (the ability to estimate a slight change in sound speed) of average sound speed estimation, after the phantom was taken out of the refrigerator, we estimated the change in sound speed over time. This change in sound speed is caused by the change in temperature of the phantom (chicken liver part), when the temperature of the phantom approaches room temperature.

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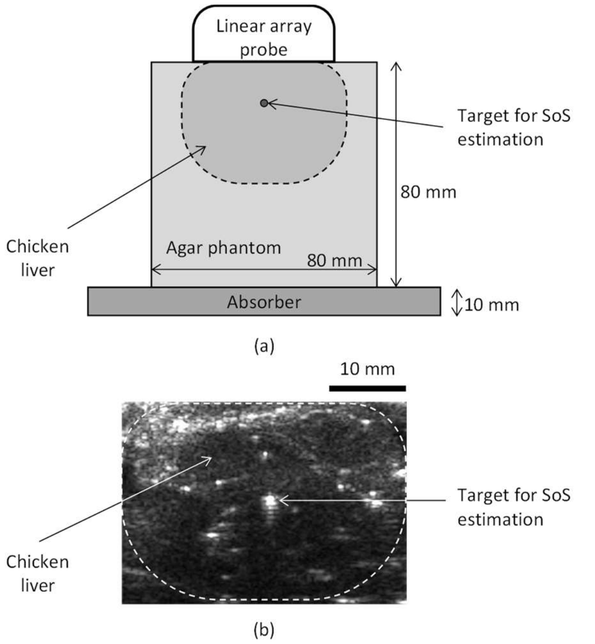

Fig. 1 (a) A setup for ex vivo experiment of the improved focusing method. (b) B-mode image of the chicken liver (dashed line).

4. Result

Figure 2 shows the process of average sound speed estimation in the phantom immediately after being taken out of the refrigerator. Figure 2(a) shows the wavefront of channel data before the time delay correction, and Fig. 2(b) shows the wavefront of channel data after the time delay correction based on the estimated sound speed. Figure 2(c) is the focusing map when c_{TEST} was varied from 1300 to 1800 m/s, and Fig. 2(d) represents the final determination of the sound speed in the liver. As shown in Figs. 2(a) and 2(b), many spurious echoes appeared other than the strong scatterer, but in Figs. 2(c) and 2(d), the average sound speed in the liver could be estimated.

Figure 3 shows the relationship between the elapsed time after taking out the phantom from the refrigerator and the estimated sound speed. When the temperature of the phantom (chicken liver part) approaches room temperature, the sound speed also changes slightly. In this experiment, such a slight change in sound speed could be estimated by using the improved focusing method.

5. Conclusion

In this study, we conducted the ex vivo experiment using an excised chicken liver to verify the applicability of the improved focusing method to actual tissues. As a result, the improved focusing method estimated slight changes in the sound speed and enabled highly accurate sound speed estimation even for the actual tissue.

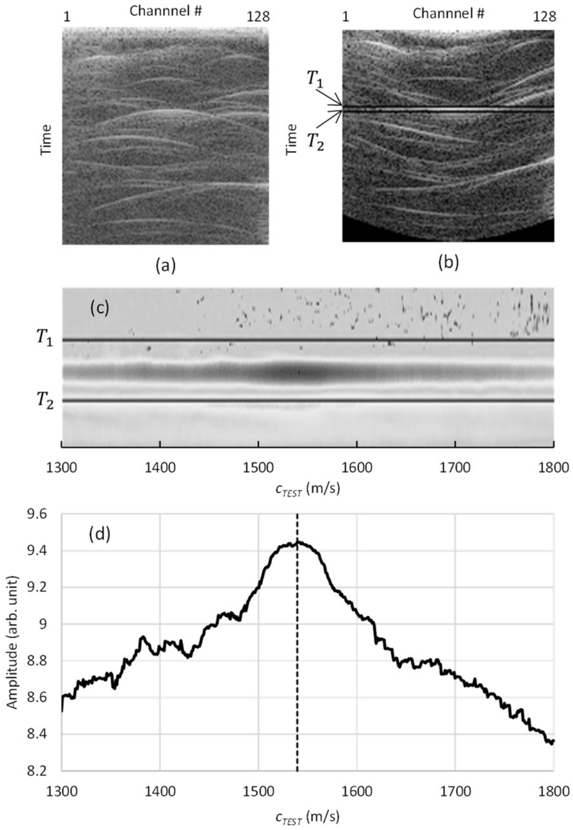

Fig. 2 The process of sound speed estimation using the improved focusing method. (a) Wavefront of channel data before the time delay correction, (b) wavefront of channel data after the time delay correction, (c) focusing map for estimation, and (d) final determination of average sound speed of the liver.

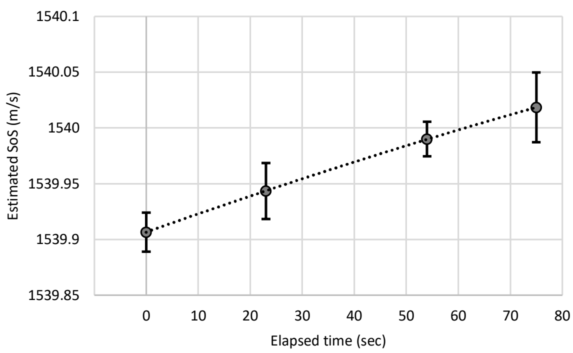

Fig. 3 The relationship between the estimated SoS and elapsed time.

Acknowledgment

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References

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2. N. Nitta et al.: Jpn. J. Appl. Phys. 61 (2022) SG1023.