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Quantitative assessment of fat content by ultrasonic velocity change method using a combined ultrasonic probe
超音波速度変化検出のための一体化プローブによる脂肪割合の定量評価

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1. Introduction

Fatty liver disease is defined as the condition in which fat makes up 5 - 10 % of the organ weight. If fatty liver progresses, it may increase the risk of cirrhosis of the liver and liver cancer. Hence, diagnosis of early-stage fatty liver is very important. Various imaging methods, including ultra-sonography (US), computed tomography (CT), magnetic resonance imaging (MRI), and proton magnetic resonance spectroscopy (MRS), have been used for the non-invasive evaluation of steatosis. However, the evaluation accuracy of those imaging methods is not sufficient for the diagnosis of fatty liver in an early stage.

We have therefore investigated a simple and non-invasive ultrasonic velocity change (UVC) method, which is based on the difference in temperature dependence of the ultrasonic velocity on propagation media. We succeeded in identifying fatty liver phantoms with different fat content rates using the UVC method.[1)] In that case, we used a combined ultrasonic probe made up of two transducers for warming a disease part and for detecting echo-signals. However, because the two transducers ware placed in same plane, the diameter of the signal-detecting transducer becomes small, resulting in the sensitivity reduction.[2)] In this research, we developed an improved combined probe composed of two transducers faced orthogonally to each other to increase the sensitivity of the transducer.

2. Ultrasonic velocity-change (UVC) method

The temperature change rate of the ultrasonic velocity in water is +1.9 m/s/deg C around body temperature and that in fat is –4.9 m/s/deg C. The relation among ultrasonic velocity-change Δv, temperature change ΔT, and fat content rate x [%], is shown in the following equation.

$$\frac{\Delta v}{\Delta T} = 1.9\left(1 - \frac{x}{100}\right) - 4.9\frac{x}{100} \qquad (1)$$

Δv is estimated from echo signals acquired before and after warming. To assess a fat content rate, it is necessary to adjust experimental conditions so that ΔT becomes constant, because ΔT is difficult to measure.

3. Configuration of combined ultrasonic probe

Figure 1 shows the structure of a combined ultrasonic probe composed of two ultrasonic transducers. Lower-frequency (1 MHz) transducer for warming the diseased part was placed at the top of the combined probe, and higher-frequency (5 MHz) transducer for detecting echo-signals was placed at the side. Under considerations of the excitation of Lamb waves and the total reflection of ultrasonic waves, a 0.7 mm-thick aluminum plate was placed in water with an angle of 45 degree to both ultrasonic waves. As a result, 1 MHz ultrasonic waves well passed through the aluminum plate, while 5 MHz ultrasonic waves were almost totally-reflected at the boundary between the aluminum plate and water. Hence, the two ultrasonic waves propagated coaxially, which enabled to match the warming area and the signal-detection area.

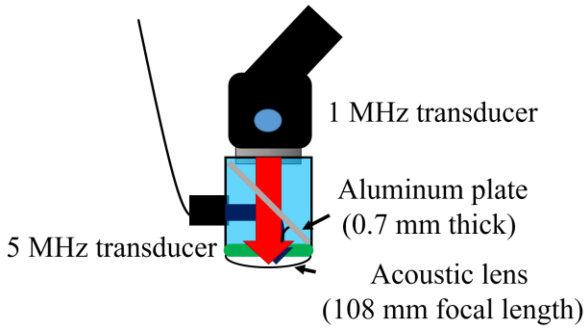

Fig. 1 Configuration of a combined ultrasonic probe composed of two transducers.

4. Experiments

4-1. Temperature change distribution in a TMM phantom

We conducted experiments to investigate warming performance of the combined ultrasonic probe. The flat temperature change distribution (ΔT is constant) is necessary to estimate the fat content rate x from $\Delta v/\Delta T$ in Eq. (1). The TMM phantom (OST, 0.7 dB/cm/MHz) was warmed with the 1 MHz transducer having an acoustic lens with a focal length of 108 mm as shown in Fig. 1. The acoustic intensity and the warming time of the 1 MHz ultrasonic transducer were set to 0.7 W/cm^2 and 60 s, respectively. As the ultrasonic property of the TMM phantom was similar to that of water, the obtained ultorasonic velocity changes were transformed into temprature changes using the known value of the ultorasonic velocity change of water per deg C around room temperature (+1.6 m/s/deg C).

Figure 2 shows the estimated temperature change as a function of a distance from the top surface of the TMM phantom. The temperature change along the central axis of the 1 MHz transducer was found to be approximately constant of about 2.0 deg C.

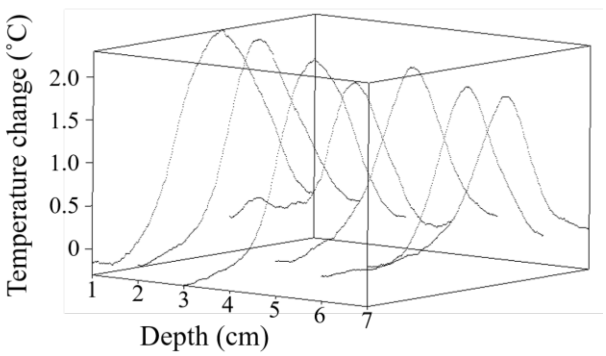

Fig. 2 Temperature change distribution in the TMM phantom.

4-2. Quantitative assessment of fat content rates of fatty liver phantom

Figure 3 shows the experimental setup to assess the fat content rate of the fatty liver phantom. The TMM phantom of 6 cm thick was placed on fatty liver phantoms (OST, 1-2 cm thick) of fat content rates of (a) 10, (b) 20 and (c) 30 %. **Figure 4** shows the experimental results of ultrasonic velocity change along the depth direction in the phantom. The condition of the 1 MHz warming transducer was the same as the case in Fig. 2. By substituting the observed values of Δv ((a) 1.7, (b) 0.65, and (c) -0.84 m/s) and a constant value of ΔT = 2 deg C into Eq. (1), the fat content rates x of (a) 11.5 %, (b) 19.6 %, and (c) 31.1 %, respectively, were estimated, corresponding well to the given fat content rates.

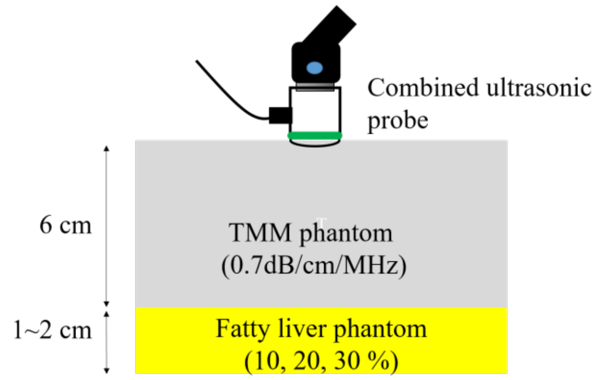

Fig. 3 Experimental setup to assess fat content rates of the fatty liver phantoms.

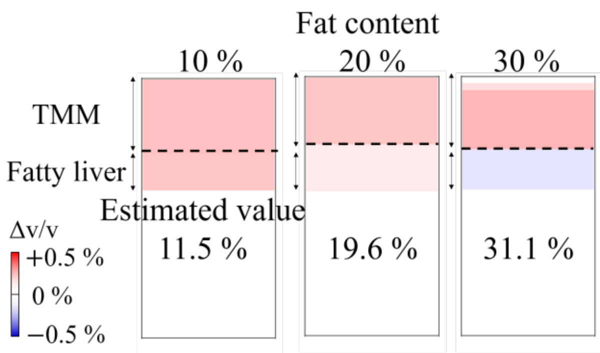

Fig. 4 Ultrasonic velocity change rates along the depth direction and quantitative assessment of fat content rates.

5. Conclusion

To develop a diagnostic equipment of early-stage fatty liver using the ultrasonic velocity change (UVC)method, a combined ultrasonic probe composed of two kinds of ultrasonic transducers for warming disease parts and detecting echo signals was designed and fabricated. By performing the UVC method using the combined probe, it was found that an approximately flat temperature change distribution was formed along the central axis of the warming transducer within the depth of 7 cm, and fat content rates of fatty liver phantoms placed at the depth of 6 cm were estimated almost exactly.

References

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