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Development of coaxial ultrasonic probe for fatty liver diagnostic system based on ultrasonic velocity-change
超音波速度変化による脂肪肝診断装置のための同軸型超音波プローブの開発

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1. Introduction

Fatty liver is a disease caused by the excess accumulation of fat in the human liver. The diagnosis of early-stage fatty liver is very important, because fatty liver is linked to metabolic syndrome. We have shown that the fat distributions in both the tissue mimic phantom and the liver of living rabbits were clearly displayed by ultrasonic velocity change imaging method. [1,2]

To obtain the value of the ultrasonic velocity change, it requires two kinds of ultrasonic transducers for warming and for transmitting and receiving ultrasonic signals.

In this study, we fabricated the coaxial ultrasonic probe by integrating two kinds of transducers. The probe is compact and has the simple structure. We applied this probe to the experimental fatty liver diagnostic system based on ultrasonic velocity-change method and studied basic characteristics of the system using TMM (the tissue mimicking material) phantom and the fatty liver phantom.

2. Ultrasonic velocity-change method

The ultrasonic velocity change Δv, which is caused by the temperature change in the fat sample is calculated from the interval between echo signals before warming τ, the echo signal shift after warming Δτ and the average ultrasonic velocity v,

$$\Delta v/v=\Delta\tau/\tau \qquad (1)$$

The temperature change rate of the ultrasonic velocity in water is +1.9m/(s·deg) and that in fat is −5.0m/(s·deg) around body temperature. The ultrasonic velocity change Δv by the temperature change ΔT is represented as,

$$\Delta v/\Delta T=(\Delta v/\Delta T)_w \cdot (1-x)+(\Delta v/\Delta T)_f \cdot x \qquad (2)$$

where x is the fat content, $(\Delta v/\Delta T)_w$ is the temperature dependence of ultrasonic velocity in water, and $(\Delta v/\Delta T)_f$ is that in fat. For the quantitative assessment of fat content, ΔT is required as well as Δv as shown in eq.(2) under the flat temperature change along the central axis direction of the warming transducer.[3)]

3. Structure of the coaxial ultrasonic probe

Figure 1 shows the structure of the coaxial ultrasonic probe. Acoustic lens (108mm focal length) is attached to the ultrasonic transducer (35 mm in diameter, 1MHz) for warming of the target region. The acoustic lens is used to get the flat temperature change distribution along the central axis direction of the warming transducer. The needle type transducer for transmitting and receiving ultrasonic signals (8mm in diameter, 5MHz) is embedded in the center of the acoustic lens.

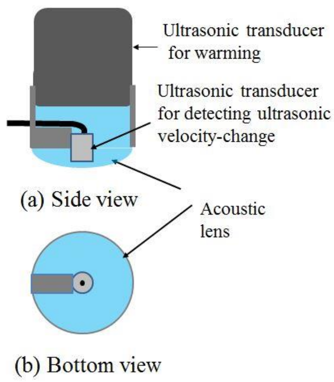

Fig.1 Structure of the coaxial ultrasonic probe

4. Experiments

4-1. Temperature change distribution in TMM phantom

We conducted experiments to investigate the warming performance of the coaxial ultrasonic probe. The flat temperature change distribution is necessary to estimate the fat rate x from $\Delta v/\Delta T$ in eq.(2).

The TMM phantom (0.7dB/cm/MHz, OST) was used in this experiment. The TMM phantom was warmed by the transducer with acoustic lens as shown in Fig.1. The intensity of the warming ultrasonic transducer was $0.7 W/cm^2$ and the warming time was 60s. As the ultrasonic property of the TMM phantom was similar to that of water, we considered only the temperature change rate (+1.6m/(s·deg)) to convert the ultrasonic velocity changes of the TMM phantom into the temperature changes. [3,4] Thus, the estimated temperature change distributions were calculated along the depth direction.

Figure 2 shows the estimated temperature change as a function of distance from the contact surface between the transducer and TMM phantom. The temperature change along the central axis of the warming transducer was approximately flat.

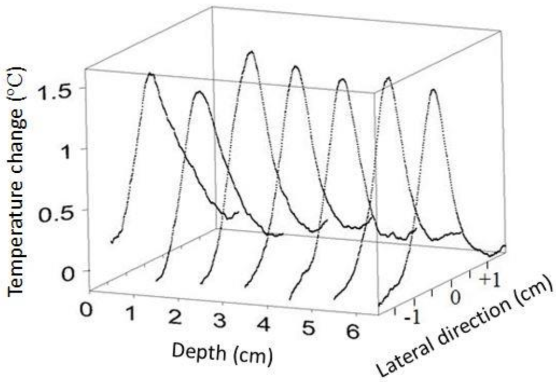

Fig.2 Temperature change distribution in the TMM phantom

4-2. Fat rate of fatty liver phantom

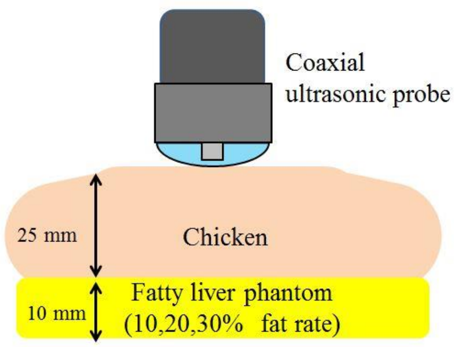

Fig.3 Experimental setup to assess the fat rate of the fatty liver phantom

Figure 3 shows the experimental setup to assess the fat rate of the fatty liver phantom. The chicken meat of 25mm thickness was used in substitution for the soft tissue. It covered each fatty liver phantom (OST) of fat content of 10%, 20% and 30%.

Figure 4 shows the experimental results of ultrasonic velocity change along the depth direction in the phantom. The intensity of ultrasonic transducer was $0.7 W/cm^2$ and the warming time was 60s.

Ultrasonic velocity change rate in the region of the chicken is approximately constant. Values of ultrasonic velocity change rate in the fatty liver phantoms, +0.11%, +0.04% and -0.02% correspond to the respective setup values of fat rate in the fatty liver phantom.

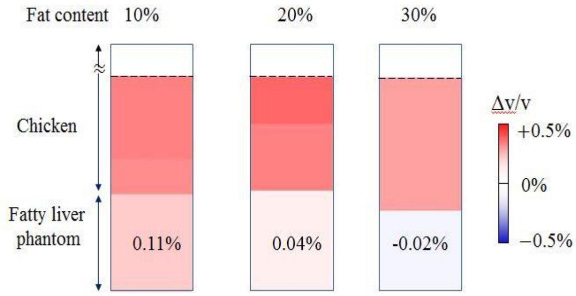

Fig.4 Ultrasonic velocity change rate of the fatty liver phantoms along the depth direction

5. Conclusion

The coaxial ultrasonic probe by integrating two kinds of ultrasonic transducers for warming and detecting of the echo signal was proposed to use the fatty liver diagnostic system. The flat temperature change distribution was formed along the depth direction of the TMM phantom. The ultrasonic velocity change corresponding to the fat rate in the fatty liver phantom inserted under the chicken meat was obtained, Experimental results showed the usefulness of the coaxial ultrasonic probe for the fatty liver diagnostic system.

References

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