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Ultrasonic measurement of temperature distribution of biological tissue by local heating
生体組織の局所加熱による温度上昇分布の超音波計測

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1. Introduction

It is well known that an ultrasonic diagnosic equipment offers a cross-sectional image noninvasively in a real time format. Recently, ultrasonic tissue characterization has been widely studied to obtain the clinical information of pathological states. This study concentrates on a heat capacity per unit volume (C_v) for tissue characterization.

C_v is considered as one of the appropriate parameters for tissue characterization because this value varies in the state of tissue. In a short time heating, C_v is convenient to write the bio-heat transfer equation as follows;

$$C_v = \frac{2\alpha I}{\dot{T}} \quad (1),$$

where α is attenuation constant, I is sound intensity, T is temperature of the tissue [1]. As heating causes degeneration of protein in tissue, from the safety point of view, it is important to measure the temperature rise within 4 ˚C. We aim to measure this temperture rise of tissue by ultrasonic waves.

This study estimated temperature rise of tissue-mimicking phantom by measuring sound velocity from the echo signals and compared the values with those measured by thermocouple.

2. Method of temperature rise measurement

The temperature rise of the biological tissue can be measured by detecting time-shifts between two ultrasonic pulse-echo signals before and after heating because sound velocity changes due to temperature rise by neglecting the tissue movements. The relation between sound velocity change $\Delta c(x)$ at x and the difference of time shifts $\Delta\tau$ is expressed as follows;

$$\Delta c(x) = c(x)\frac{\Delta\tau}{\Delta t} \quad (2),$$

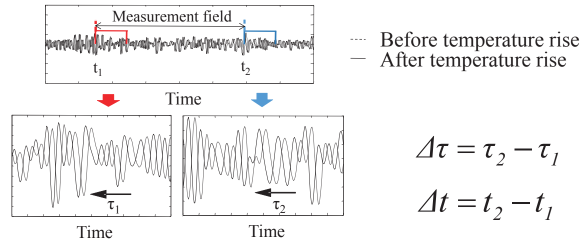

Fig. 1 Schematic illustration of estimates of sound velocity change from time-shifts of echo signals.

where $c(x)$ is sound velocity at x before heating and Δt is the diffrence of time between two gates as shown in Fig. 1.

3. Signal processing

The time-shift τ in the echo signals caused by temperature rise is calculated by combining with two methods as follows; cross-correlation method and auto-correlation method, since the measurement by the former method is not sufficient accuracy and by the latter method is not sufficient range.

3.1 Cross-correlation method

The time-shift τ can be computed by shift of correlation peak of the echo signals multiplied by window function between before and after heating.

3.2 Auto-correlation method

After quadrature detection of the echo signals multiplied by window function, the value of τ is calculated by the averaged phase of auto-correlation function [2].

4. Experiments

4.1 Tissue-mimicking material

A tissue-mimicking material (TMM) based on standard of IEC60601-2-37 is used for the experiments. The size of TMM is 60×70×100 mm^3.

4.2 Measurement of temperature rise

Fig. 2 shows the experimental systems. Ultrasonic pulse-echo measurements were performed using Pulser/Receiver (MODEL 5072,

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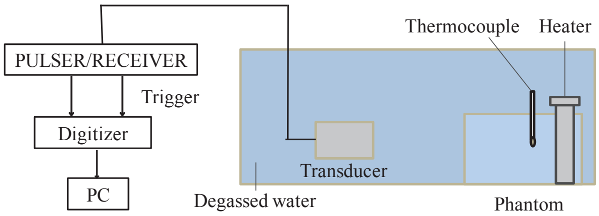

Fig. 2 Experimental system.

OLYMPUS) and concave transducer (B5C10IPF50, JAPAN PROBE, 10 mm in diameter with a focal length of 50 mm, resonance frequency is 5 MHz). Thermocouple (VT1, CHINO, $\Phi = 0.1$ mm) was fixed at the focal point of transducer in the TMM and a heater (M131695, NIPPON HEATER) was fixed in the TMM as shown in Fig.2. The echo signals were digitized and recorded by a waveform digitizer (CS8329, Gage, 100 MS/s, 14 bits) and the values measured by the thermocouple were also digitized and recorded at every 30 seconds.

5. Results and Discussion

Fig. 3 shows the relationship between temperature rise and sound velocity change in TMM. This result indicated the temperature coefficient of TMM was 2.7 m/s/°C.

Fig. 4 shows the temperature rise vs. time measured by the thermocouple and the ultrasonic method. The diffrence between two values were significant, because the measurement points are different. Values measured by the thermocouple were at the focal point but values measured by ultrasonic method were averaged over a region defined by the sound field formed by the transducer and the initial conditions of the signal processing. The averaged region was estimated as a cylinder of $2\phi \times 10$ mm^3.

Fig. 5 is the temperature rise subtracted the values at 270 sec. These two values are in good agreement.

6. Conclusion

This study proposed a method for measurement of temperature rise in tissue by using ultrasonic pulse-echo signals. The experiments using a TMM by local heating were carried out. As a result, it is shown the possibility of measurement of temperature rise in tissue by using ultrasonic waves.

Acknowledgement

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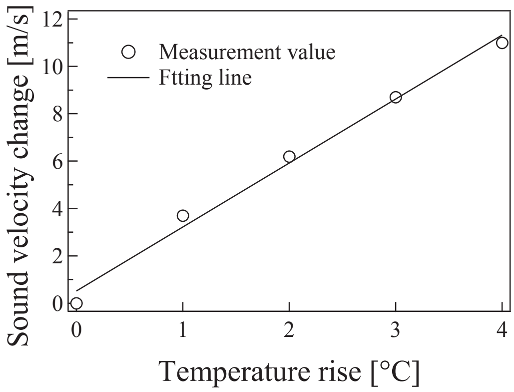

Fig. 3 The relationship between temperature rise and sound velocity change in TMM.

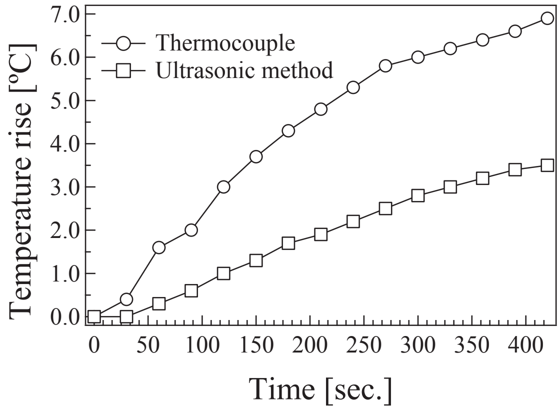

Fig. 4 The temperature rise vs. time. The values were measured by using thermocouple and ultrasonic waves.

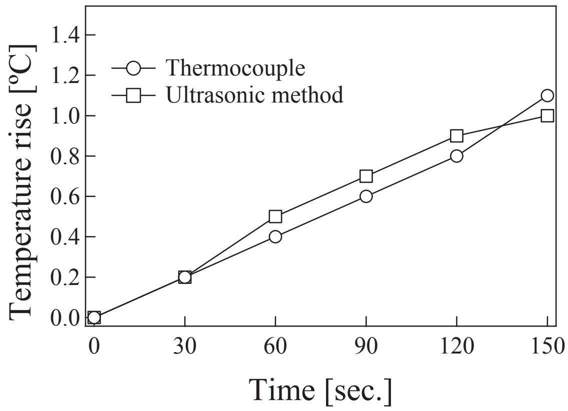

Fig. 5 The temperature rise vs. time. The tempeture rise subtracted the values at 270 sec. They were measured by using thermocouple and ultrasonic waves.

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