3P5-18

Measurement of temperature dependence of sound velocity for biological tissues

生体組織における音速の温度特性の測定

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1. Introduction

A transcatheter arterial chemo-embolization (TACE) using Lipiodol® is a significant technique for hepatocellular carcinoma treatment. In this technique it is important to monitor the Lipiodol® densely deposited inside tumors. As a biological tissue is exposed to ultrasound, the temperature rises depending on the physical quantity inherent to the tissue's conditions such as specific heat, thermal diffusion coefficient, atteuation coefficient as well as ultrasonic intensity[1-3]. Tissue characterization by using rate of temperature rise due to ultrasonic heating has been proposed[2]. This method has a potential to evaluate *in vivo* the Lipiodol® densely deposition inside tumors, since the Lipiodol® comprises poppy-seed oil. In general the temperature dependence of oil is negative and that of non-fat tissue is positive. Thus, it is significant for the proposed method to show the temperature dependence of sound velocity of Lipiodol® and cancer tissue. The aim of this study is to measure sound velocity as a function of temperature for Lipiodol® and extracted tumors of rat liver cancer. This method uses sound velocity change exposed to ultrasound up to 1 - 3 ˚C rise in temprature, the temprature coefficient of sound velocity is required at body temperature. Since the temperature coefficient in the range from room temperature to body temperature, the range of sound velocity change is about 15 - 45 m/s, that is 1 - 3 %. Therefore this study discusses a method for measurement of temprature dependence of sound velocity including measurement accuracy.

2. Material and methods

An ultrasonic pulse echo method was used for a measurement of sound velocity in this study, since an experimental system is configured by one transducer. According to the pulse echo method, the sound velocity is calculated from the propagation distance divided by a time of flight of ultrasonic propagation. As increasing temperature, the temperature distribution is required as uniform in a specimen for the preserved accuracy, since sound velocity is measured as an averaged value within the ultrasonic beam in the specimen. Thus, it is decided to take a few hours to increase the temperature of 10 ˚C in an incubator. The incubator (CN - 40A, Axel), which is a natural convection type and equipped with Peltier elements for heating and cooling is decided to use in the experiments.

Since the change in sound velocity during the temperature rise from room temperature to body temperature is about 15 - 45 m/s, the accuracy of measurement of sound velocity is required to be less than 1 %. It is difficult for the tissue sample to cut 5.00 mm in thickness within 1 % of accuracy. The specimen was put into the depression of 5.00 mm in depth located in a center of an acrylic block. An aluminum block was put on the specimen to preserve the thickness of 5.00 mm within 1 % accuracy as shown in **Fig. 1**. The sampling interval of the echoes was decided as 0.4 ns to be the error rate of sound velocity less than 1 %. An aluminum was used because the thermal conductivity is 236 W/m/K higher than that of acrylic of 0.21 W/m/K. The thickness of the aluminum block was set at 50 mm to avoid the interferences of echoes from the specimen and the multiple reflections between the surface of the aluminum block and the surface of the transducer.

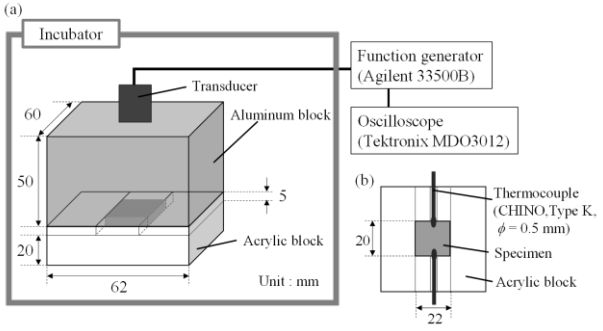


Fig. 1 Experimental setup.

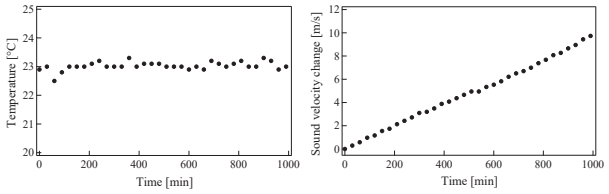
A planar transducer (B5K10I, JAPAN PROBE) of 10 mm in diameter, 5 MHz in resonance frequency was fixed on the top of the aluminum block to receive the echoes from the specimen. The transducer was driven by one cycle sinusoidal wave of 5.0 MHz and 10.0 $V_{p\text{-}p}$. The echo signals were received by the transducer and were digitized in 8

bits and 2.5 GHz in sampling by an oscilloscope (Tektronix, MDO3012). The temperature was measured by two thermocouples (Chino, K - type) of 0.5 mm in diameter inserted into the specimen as shown Fig. 1 (b).

3. Results and Discussion

First of all temporal stability was measured by using bovine liver as a tissue sample, since it takes a few hours to complete the measurement. The relation of measured temperature and sound velocity to elapsed time by neither exposure to ultrasound nor operation of temperature are shown in **Fig. 2 (a)** and **Fig. 2 (b)**, respectively. As shown in these figures, the sound velocity was increased at 1.0×10^{-2} m/s a minute. Thus the time of measurement was decided to 180 minutes to preserve the accuracy as less than 1 %. Then, the temperature distribution was measured to confirm the uniformity inside the sample. **Fig. 3** shows the temperature fluctuation close to the edge and the center of sample. It is found that the temperature rise at the center and the edge was agreed within 1 %. As shown in **Fig. 4**, the temperature coefficient of sound velocity was calculated by line fitting in the range where the temperature rise rate was constant. The calculated value was 1.1 m/s/˚C.

Fig. 5 and 6 show the relation of sound velocity change to the temperature for Lipiodol® and a specimen of rat liver cancer, respectively. The calculated temperature coefficient of sound velocity for Lipiodol® and the cancer was -2.8 and 1.6 m/s/˚C, respectively.



(a) (b)

Fig. 2 (a) Relationship of temperature and elapsed time in bovine liver. (b) Relationship of sound velocity and elapsed time in bovine liver.

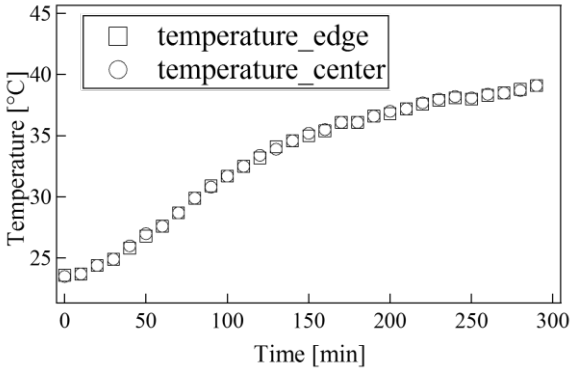


Fig. 3 Temperature at edge and center in bovine liver.

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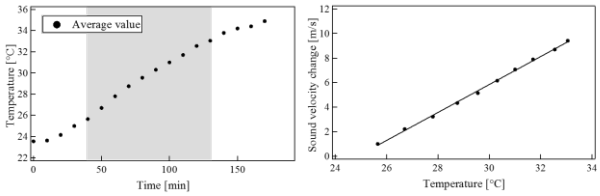

(a) (b)

Fig. 4 (a) Relationship of temperature rise and elapsed time. (b) Temperature coefficient of sound velocity for bovine liver.

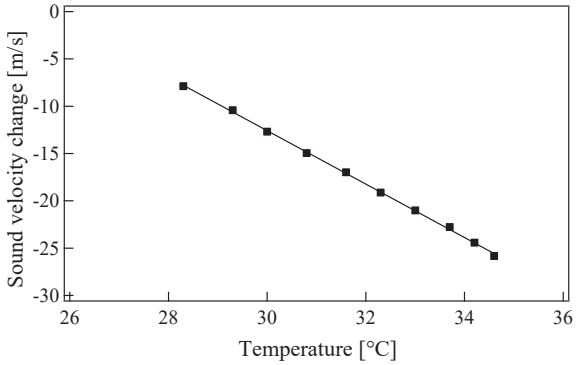

Fig. 5 Relation of sound velocity to temperature for Lipiodol®.

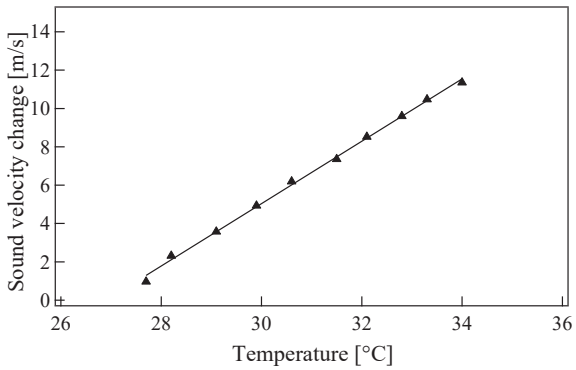

Fig. 6 Relation of sound velocity to temperature for rat liver cancer.

4. Conclusion

This study proposed a method to measure the temperature dependence of sound velocity and showed measured values of rat liver cancer and Lipiodol® as 1.6 m/s/˚C and -2.8 m/s/˚C, respectively.

Acknowledgment

This study is supported by MEXT - Supported Program for the Strategic Research Foundation at Private Universities, 2013 - 2017.

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