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Measurement of Internal Temperature in Biological Tissue by Statistical Analysis of Ultrasonic Scattered Echoes

超音波散乱波の統計的解析による生体組織内温度測定

Michio Takeuchi[1†], Yuta Matsui[1], Tatsuro Doi[1], Yoshiyuki Takano[1], and Hideyuki Hasegawa[2] ([1]TATEYAMA KAGAKU DEVICE TECHNOLOGY CO., LTD.; [2]Graduate School of Science and Engineering for Research, Univ. of Toyama)
竹内道雄[1†]，松井裕太[1]，土井達郎[1]，高野義之[1]，長谷川英之[2] ([1]立山科学デバイステクノロジー, [2]富山大学大学院理工学研究部)

1. Introduction

Developments of practical methods and instruments for non-invasive detection of internal body temperature is crucial for medical diagnosis and treatment. Especially the demand for non-invasive temperature measurement has been increasing in hyperthermia therapy for cancer treatment recently because the most important parameter to be monitored and controlled during the therapy is the temperature of malignant tumor under heating. Nevertheless there is still no practical method for detection of the temperature during therapy. It's well known that only a method using magnetic resonance imaging (MRI) is an successful attempt of detecting internal body temperature.[1)] However, unfortunately the method is not convenient for monitoring hyperthermia therapy because of some issues (e.g., cost of MRI instrument, size, strong magnetic field generated by MRI instrument, etc.)

To fulfill the demand for non-invasive internal temperature measurement mentioned above, in the present study, we investigated a method for measurement of internal temperature by statistical analysis of ultrasonic scattred echoes. Also, the feasibility of the proposed method was evaluated by an experiment using a soft tissue mimicking phantom.

2. Materials and Methods

2.1 Experimental setup

In the present study, a cylindroid agar phantom with glass beads of several tens of micrometers in diameter (59200U, Spelco Bellefonte, PA, USA) was prepared as a soft tissue mimicking material by referring to recipes in the literature.[2,3)] It is expected that the agar phantom has 32 scatters per cubic millimeter. We wrapped flexible electrodes around the phantom in order to increase temperature of the phantom from 20.0 deg. C up to 42.0 deg. C owing to radio-frequency (RF) heating using a thermal therapy device (*i*-Booster, TATEYAMA KAGAKU INDUSTRY CO., LTD., Toyama, Japan). Temperature measurement was performed by a flexible fiber optic thermometer (m3300, Luxtron, CA, USA). The temperature sensor was selected to avoid being heated due to RF heating. Ultrasonic scattered echoes from the phantom were measured at 0.5 deg. C intervals by an ultrasonic measurement system (RSYS0002, Microsonic, Tokyo, Japan) with a linear array transducer (UST-5412, Hitachi, Tokyo, Japan). The experimental setup is illustrated in Fig. 1. Also, parameters in the ultrasonic measurement of the phantom are listed in Table 1.

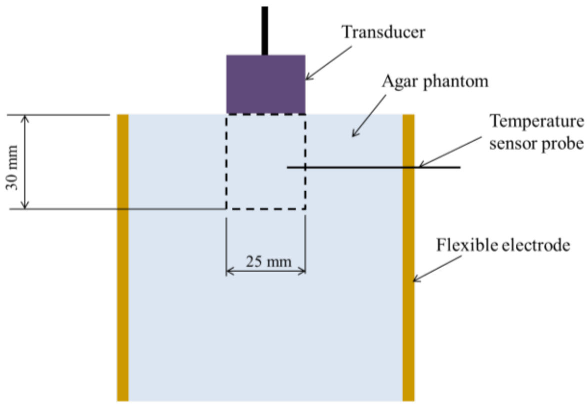

Fig. 1 Cross-section of experimental setup

Pitch of scan lines	200 μm
Number of scan lines	121
Number of samples per scan lines	1200
Central frequency	7.5 MHz
Wave length	0.2 mm
Sampling rate	31.25 MHz

Table 1 Parameters in ultrasonic measurement

2.2. Analysis and Discussion

In the present study, we made use of Nakagami *m* factor in statistical analysis of ultrasonic echoes to observe internal temperature changes of the tissue mimicking phantom. The Nakagami distribution function is expressed as

† m-take@tateyama.or.jp

$$f(r)=\frac{2m^m r^{2m-1}}{\Gamma(m)\Omega^m}\exp\left(-\frac{m}{\Omega}r^2\right)U(r), \qquad (1)$$

Where $\Gamma(\cdot)$ and $U(\cdot)$ are the gamma function and unit step function, respectively, m is Nakagami parameter, and Ω is a scaling parameter.

In signal processing of this study, the Hilbert transformation was applied to measured ultrasonic scattered echoes in each scan line, and the envelope was obtained. Then, we calculated Nakagami m factor by fitting the Nakagami distribution function to the statistical distribution of the envelope of the ultrasonic echo signal in each ROI (ROI size is 0.6 mm × 0.6 mm). Meanwhile, B-mode images were obtained from the ultrasonic scattered echoes.

3. Results and Discussion

Mean values of m parameter plotted as a function of temperature are shown as Fig. 2. The mean values of m factor slightly decrease with increasing temperature. The behavior of the m parameter is coincided with the result reported by Gambin and Kruglenko.[4] Although the average value of m parameters decreased with increasing temperature, not all of ROIs have the same tendency and the change in the m parameter is considerably small. Therefore, we calculated the absolute values α of the ratio changes of m values during heating as follows.

$$\alpha = \left|10\cdot\log_{10}\left(\frac{m_T}{m_{T_R}}\right)\right|, \qquad (2)$$

Where m_{TR} and m_T are m factor at a reference temperature and m factor at each temperature, respectively. In this work, the reference temperature was set at 36.0 deg. C because we intend to use the proposed method in the human body temperature range. Therefore, we made hot-scale images indicating amplitude of ratio changes of m values at respective temperatures in Fig. 3. In Fig. 3, the conventional B-mode image and hot-scale m-parameter images at temperatures from 36.0 deg. C to 42.0 deg. C of the phantom are described. The internal temperature change of the phantom is obviously observed in the hot-scale images. Moreover, small temperatures change ΔT of 0.5 deg. C is also confirmable in the images.

4. Conclusion

We presented the results of detecting the internal temperature change of a soft tissue mimicking phantom by statistical analysis of ultrasonic scattered echoes. A statistical parameter, Nakagami m factor, showed slight changes with increasing temperature of the soft tissue mimicking phantom. The internal temperature changes were distinctly observed in hot-scale images obtained by calculating the ratio changes of m values during heating. The experimental results suggest that that the change in the statistical parameter m reflects a quite small thermal strain of the phantom.

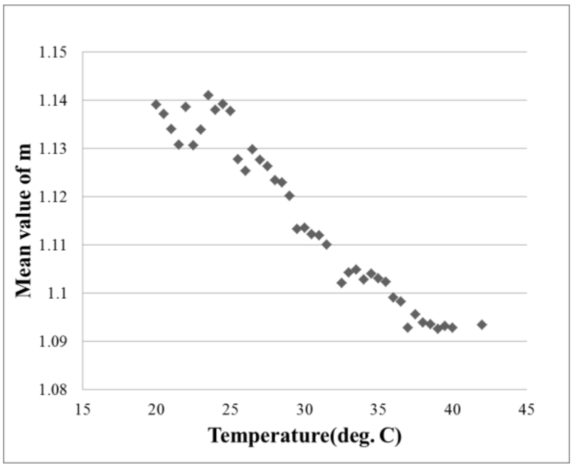

Fig. 2 Temperature dependence of mean value of m

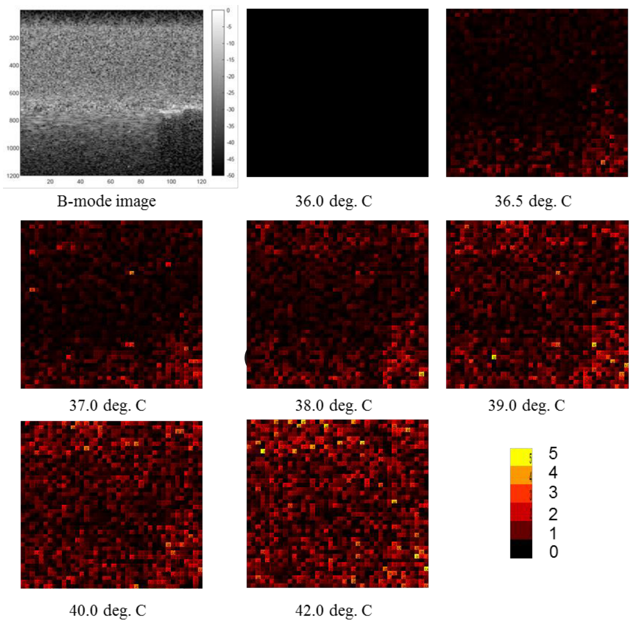

Fig. 3 Gray-scale B-mode image of phantom and hot-scale images indicating absolute values of ratio changes of m values at respective temperatures.

References

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