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Non-invasive measurement of temperature elevation inside tumor tissue during oncological hyperthermia treatment by statistical analysis of ultrasonic scattered echoes

超音波散乱波統計解析による癌温熱治療中の腫瘍組織内温度上昇の非侵襲測定

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1. Introduction

Hyperthermia therapy is one of the most patient-friendly cancer treatments in terms of side effects. However, oncological hyperthermia treatment has not been the mainstream therapy. One of the most acute causes hindering the growth of oncological hyperthermia therapy is a lack of a realistic method of non-invasively monitoring internal body temperature distribution during heating.

Many research groups have been focusing on the study of non-invasive measurement of internal human body temperature with acoustic methods. Especially, the method using the temperature dependence of ultrasound propagation speed achieved detecting temperature inside biological tissue specimens. However, it is unrealistic to apply the method to *in vivo* situations because ultrasound propagation path length changes due to body motion and pulsation during heating in *in vivo* situation. On the other hand, a novel acoustic method with statistical parameters obtained from statistical analysis of ultrasound backscattered echoes was proposed for tissue characterization. In particular, it was reported that the Nakagami shape parameter m has a dependence on the scatterer concentration in the medium.[1)] The study result implies that the Nakagami shape parameter m reflects infinitesimal thermal expansion and contraction of the medium, and thereby the Nakagami shape parameter m has a potential being an indicator of temperature changes inside biological tissue specimens. Our research group reported that a temperature elevation inside biological tissue specimens with thermal displacement can be detected by specific parameter α indicating absolute values of ratio changes of m values estimated with a proper size of a region of interest (ROI) considering the amount of thermal displacement of soft tissue.[2)] Moreover, we found that the magnitude of the variation in the Nakagami shape parameter (Δm) due to a temperature increase has an initial m-value dependence and Δm due to a temperature rise increases with increasing the initial m-value.[3)] Hence, we extended the sensitivity of α by introducing the multiplying factor γ varying as a function of the initial m-value in order to calculate absolute values of ratio changes of m values with compensation of the difference of Δm depending on the initial m-value, $\alpha_{\mathrm{mod.}}$.[3)] Furthermore, we showed that the temperature elevation inside the abdominal cavity and tumor tissue of a living rat induced with capacitive-coupled radiofrequency (RF) heating can be measured by our acoustic method using $\alpha_{\mathrm{mod.}}$.[4)] In this study, we present a clinical trial study result that the temperature elevation inside tumor tissue of right kidney cancer induced with RF current heating was measured by hot-scale images indicating absolute values of ratio changes of m values, $\alpha_{\mathrm{mod.}}$.

2. Experimental setup

In this study, hyperthermia therapy was carried out with an RF hyperthermia treatment equipment (Shonai Create Industrial ASKIRF-8). The cancerous patient has been diagnosed as having a right kidney cancer and the tumor tissue widely

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invading the surrounding tissue by computed tomography scan. The patient was induced by passing RF current between two water-bolus electrodes for forty minutes. The applied power was carefully controlled and increased up to 1.5 kW. Ultrasonic backscattered echoes from the tumor tissue of the right kidney cancer were measured using an ultrasonic measurement system (Microsonic RSYS-0016) with a convex array transducer (Hitachi Aloka Medical UST-9123). The initial measurement of ultrasonic echoes was conducted just the moment before applying RF current to the tumor tissues; then ultrasonic backscattered echoes were measured during heating at 2, 5, 10, and 40 minutes after applying RF current. The experimental setup is shown in Fig. 1. All procedures were approved by the ethical committee at Kouseiren Takaoka Hospital (#020212002).

Fig. 1. Experimental setup

3. Analysis and discussion

Statistical analysis of ultrasonic scattered echoes was processed by a custom-made software after the hyperthermia therapy. In signal processing with the custom made software, analytic signals were elicited from ultrasonic RF signals, subsequently, the envelope signals were calculated, and the histograms of envelopes in each ROI were created; then the Nakagami shape parameter m for each ROI were estimated by fitting the Nakagami distribution function to the histograms of the envelope.

In this study, the temperature increase inside the tumor tissue was expressed by the variation of brightness on a two-dimensional hot-scale image indicating absolute values of ratio changes of m values, $\alpha_{\mathrm{mod.}}$. The specific parameter $\alpha_{\mathrm{mod.}}$ is defined as

$$\alpha_{\mathrm{mod.}} = \left|\gamma \cdot \log_{10}\left(\frac{m_T}{m_{T_R}}\right)\right|, \quad (1)$$

where m_{TR} and m_T are the Nakagami shape parameter m at non-induced state and each minute after RF current was applied. The multiplying factor γ is defined to be proportional to m^{-1} as

$$\gamma = \frac{10}{m_{T_R}} \quad (2)$$

The gray-scale B-mode image and the hot-scale images indicating absolute values of ratio changes of m values, $\alpha_{\mathrm{mod.}}$, are shown in Fig. 2. The area enclosed with a dotted blue circle in the gray-scale B-mode image indicates the right kidney. In the $\alpha_{\mathrm{mod.}}$ maps, the increase in $\alpha_{\mathrm{mod.}}$ brightness with treatment time is observed. The increase in $\alpha_{\mathrm{mod.}}$ brightness implies a temperature elevation inside the tumor tissue of the right kidney cancer and tissue around the right kidney induced by RF current.

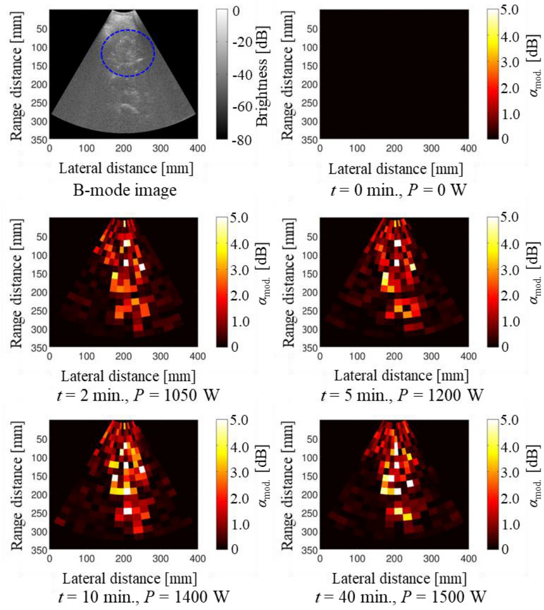

Fig. 2. B-mode image and hot-scale images indicating the absolute value of ratio changes of m values, $\alpha_{\mathrm{mod.}}$

4. Conclusion

In this clinical trial study, we presented that temperature elevation inside tumor tissue of kidney cancer induced by RF current could be detected with our acoustic method using $\alpha_{\mathrm{mod.}}$. The result indicates that the method is a promising way of non-invasively monitoring temperature elevation inside tumor tissue during hyperthermia therapy.

References

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