2Pb5-11

A basic study on ultrasound noninvasive measurement of temperature elevation inside biological tissue cauterized by radiofrequency catheter ablation

超音波非侵襲温度測定の心筋焼灼術中生体組織内温度上昇測定への適用の基礎的検討

Michio Takeuchi[1†], Toshihiko Sakai[1], Yusuke Oshima[2], Yasuhiro Kojima[2], Kenji Mori[2], Masaaki Omura[3], Ryo Nagaoka[3], and Hideyuki Hasegawa[3] ([1]Tateyama Kagaku Co., Ltd.; [2]Japan Lifeline Co., Ltd.; [3]Faculty of Eng., Univ. of Toyama)
竹内道雄 [1†], 坂井俊彦 [1], 大島祐介 [2], 小島康弘 [2], 森謙二 [2], 大村眞朗 [3], 長岡亮 [3], 長谷川英之 [3]
([1] 立山科学, [2] 日本ライフライン, [3] 富山大学学術研究部工学系)

1. Introduction

Radiofrequency (RF) catheter ablation (RFCA) is an effective therapy for a patient suffering from atrial fibrillation. In the treatment, a region producing abnormal electrical excitation in the posterior wall of the atrium sinistrum leading to atrial fibrillation is cauterized by RF current. The tissue of the atrium sinistrum is regionally heated to approximately 60 °C. Meanwhile, the wall of the esophagus firmly adheres to the posterior wall of the atrium sinistrum; hence, overheating is the cause of a fatal medical accident that is the rupture in the wall of the esophagus, esophageal fistula. In order to prevent such crucial malpractices, the temperature of the esophagus was is monitored by inserting a contact type temperature sensor array into the esophagus during RFCA. However, there have been a few serious problems in detecting the temperature of the esophagus wall with the contact type temperature sensor. One of the issues is that it is difficult to make sure whether the contact type temperature sensor is located on the region of the tissue of the esophagus wall adjacent to the ablation target region in the posterior wall of the left atrium. Other crucial issue is that the temperature detected with the contact type temperature sensor shows only the temperature of the mucosal epithelium of the esophagus. The temperature distribution inside the esophagus wall, which is approximately 4 mm in thickness, is not monitored during RFCA. Therefore, RFCA has been carried out with the risk of overheating inside the esophagus wall.

Recently, we have proposed a temperature measurement method with statistical analysis of ultrasonic scattered echoes for noninvasive detection of the temperature elevation inside tumor tissue induced by RF current heating during oncological hyperthermia.[1-3] The Nakagami shape parameter *m* varies with a change in scatterer density of the medium. The change in the *m* values reflects the volume change of the medium due to the temperature changes inside the medium.[4)] In our previous studies, we demonstrated that the temperature elevation inside tissue can be detected by the absolute values of the percentage changes in the *m* values, α_{mod}.[1-4)] In this study, we present *ex vivo* study results for demonstration of the acoustic method we have proposed to detect the temperature elevation inside the wall of the cardiac and esophagus walls during RFCA.

†m-take@tateyama.or.jp

2. Experimental setup

In this study, porcine tissue specimens consisted of two tissue layers were used. One was myocardium, and other was an esophageal wall. The porcine tissue specimen was prepared by stacking the esophageal tissue on the myocardium tissue. The tissue specimen was set in 0.45% normal saline and cauterized for 30 seconds by the RF current energy at P = 15 W using an RFCA system (Japan Lifeline JCP-50). The tip of the ablation catheter was placed at the side of

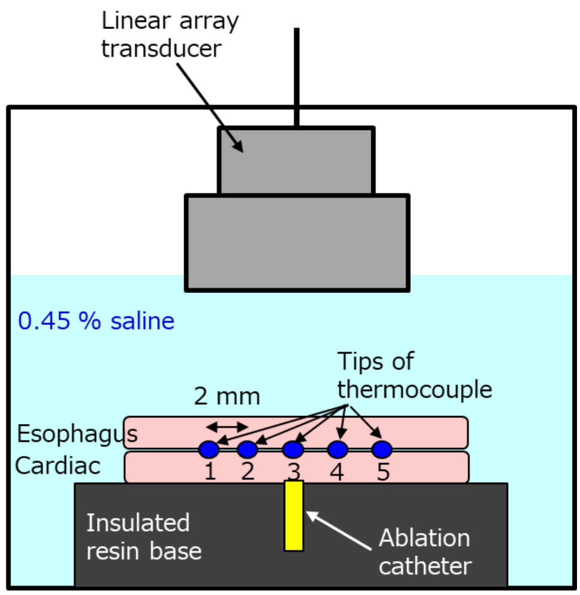

Fig. 1. Experimental setup.

myocardium of the two-layered tissue specimen. The reference temperatures at five points between the two tissue layers were measured with five thermocouple temperature sensor probes. The reference temperatures at the ablation zone of myocardium was measured by a thermocouple embedded in the tip of the ablation catheter. The experimental setup is shown in Fig. 1. Ultrasound echoes scattered from the specimen were measured at intervals of 1 milliseconds by an ultrasonic measurement system (Microsonic RSYS0016) with a linear array transducer (Hitachi UST-5412).

3. Analysis and discussion

In statistical analysis for estimating the Nakagami shape parameter m and the specific parameter α_{mod}, ultrasonic echo signals were processed off-line with custom-made software. The histograms of envelopes of the ultrasonic echo signals were created in each region of interest (ROI) by setting the ROI size at approximately 2 × 2 mm^2. The Nakagami distribution function is expressed as

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

where Γ(·) and U(·) are the gamma function and unit step function, respectively, r is the amplitude of the envelope of the ultrasonic backscattered echo, and Ω is a scaling parameter. The Nakagami shape parameters m were estimated by fitting the

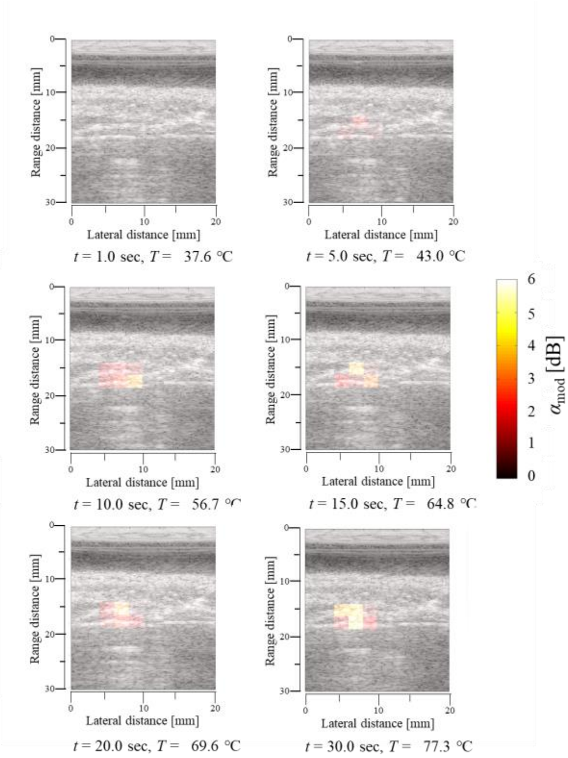

Fig. 2. Two-dimensional α_{mod} maps overlaid on grayscale B-mode images.

Nakagami distribution function to the histograms of envelopes of analytic ultrasonic signals obtained with the Hilbert transformation. The specific parameter, α_{mod}, indicating the absolute value of the percentage changes in the m values was calculated as follows:

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

where m_{TR} and m_T are the Nakagami shape parameters m at noninduced state and each time after RF current was applied. The multiplying factor γ is defined to be inversely proportional to m_{TR}:

$$\gamma = \frac{10}{m_{T_R}} \qquad (3)$$

In this study, we conducted the statistical analysis by focusing on the limited region of the cauterized tissue around the ablation catheter. The two dimensional size of the analyzed region was approximately 6 mm in width and 4 mm in height. The two-dimensional hot-scale maps of α_{mod} was overlaid on the grayscale B-mode images. Figure 2 shows the overlaid image at each time. The reference temperature shown in Fig. 2 is the temperature measured at point 3. In the overlaid images, the increase in the α_{mod} brightness around the ablation catheter with increasing the reference temperature is clearly observed. The increase in α_{mod} brightness implies a temperature elevation in the tissue of the cardiac tissue cauterized by RF current. On the other hand, the increase in the α_{mod} brightness around the esophagus wall was not observed in this study. The result suggested that the RF current did not propagate into the esophagus wall. In fact, the esophagus wall was confirmed not to be coagulated after the experiment.

4. Conclusion

In this study, we demonstrated that temperature elevation inside a cardiac tissue cauterized by RF current could be clearly visualized with α_{mod} maps. The result indicates that the method has the potential to noninvasively detect the temperature elevation in tissue during RFCA.

References

1. M. Takeuchi, Y. Matsui, T. Doi, Y. Takano, G. Andocs, and H. Hasegawa, Jpn. J. Appl. Phys. **57**, 07LB17 (2018).
2. M. Takeuchi, Y. Matsui, T. Sakai, G. Andocs, R. Nagaoka, and H. Hasegawa, Jpn. J. Appl. Phys. **58**, SGGE09 (2019).
3. M. Takeuchi, T. Sakai, G. Andocs, K. Takao, R. Nagaoka, and H. Hasegawa, Sci. Rep. **10**, 9030 (2020).
4. M. Omura, M. Takeuchi, R. Nagaoka, and H. Hasegawa, Med. Phys. **48**, 3042 (2021).