ELectronics EXpress
LETTER
IEICE Electronics Express, Vol.14, No.3, 1–6

Detection of tissue coagulation for microwave surgical devices

Naoyuki Ogasawara[1] **and Kazuyuki Saito**[2a)]
[1] *Graduate School of Engineering, Chiba University, 1–33 Yayoi-cho, Inage-ku, Chiba 263–8522, Japan*
[2] *Center for Frontier Medical Engineering, Chiba University, 1–33 Yayoi-cho, Inage-ku, Chiba 263–8522, Japan*
a) *kazuyuki_saito@faculty.chiba-u.jp*

Abstract: This paper describes the detection of tissue coagulation for a microwave surgical device. This method uses variations in the electrical properties of biological tissue before and after heating. To evaluate the proposed method, we made coagulated tissue and measured the impedance of the tissue using the microwave surgical device. The results of the measurements show that the impedance of the heated tissue changed significantly due to tissue coagulation. This results implies that coagulation of tissue can be detected by variation of electrical impedance.

Keywords: microwave, tissue coagulation, impedance, detection circuit
Classification: Microwave and millimeter-wave devices, circuits, and modules

References

[1] F. Sterzer: "Microwave medical devices," IEEE Microw. Mag. **3** (2002) 65 (DOI: 10.1109/6668.990689).
[2] M. Inoue, *et al.*: "Evaluation on heating characteristics of the microwave antenna for tissue coagulation device," Program and Abstracts 11th Int. Cong. Hyperthermia. Oncol./29th Jpn. Congr Thermal Med. (2012) 173.
[3] A. G. Mungall, *et al.*: "Measurement of the dielectric properties of blood," IRE Trans. Biomed. Electron. **8** (1961) 109 (DOI: 10.1109/TBMEL.1961.4322869).
[4] R. L. Rosenthal and C. W. Tobias: "Measurement of the electrical resistance of human blood: Use in coagulation studies and cell volume determinations," J. Lab. Clin. Med. **33** (1948) 1110.
[5] Y. Endo, *et al.*: "The development of forceps-type microwave tissue coagulator for surgical operation," IEEE Trans. Microw. Theory Techn. **63** (2015) 2041 (DOI: 10.1109/TMTT.2015.2427154).
[6] T. Sakai and S. Watanabe: "Measurement of pig tissues for complex permittivity and water contents in millimeter wave band," IEICE Tech. Rep. **110** (2010) EMCJ2010-8, 39 (in Japanese).
[7] Y. Endo, *et al.*: "Dielectric properties and water contents of coagulated biological tissue by microwave heating," IEICE Commun. Express **4** (2015) 105 (DOI: 10.1587/comex.4.105).
[8] K. Saito, *et al.*: "Heating characteristics of array applicator composed of two coaxial-slot antennas for microwave coagulation therapy," IEEE Trans.

DOI: 10.1587/elex.14.20161223
Received December 9, 2016
Accepted January 4, 2017
Publicized January 20, 2017
Copyedited February 10, 2017

Microw. Theory Techn. **48** (2000) 1800 (DOI: 10.1109/22.883857).
[9] C. Gabriel: "Compilation of the dielectric properties of body tissues at RF microwave frequencies," Brooks Air Force Technical Report AL/OE-TR-1996-0037 (1996).
[10] P. A. Hasgall, *et al.*: "IT'IS Database for thermal and electromagnetic parameters of biological tissues," Version 2.4 (July 30th, 2013) www.itis.ethz.ch/database.

1 Introduction

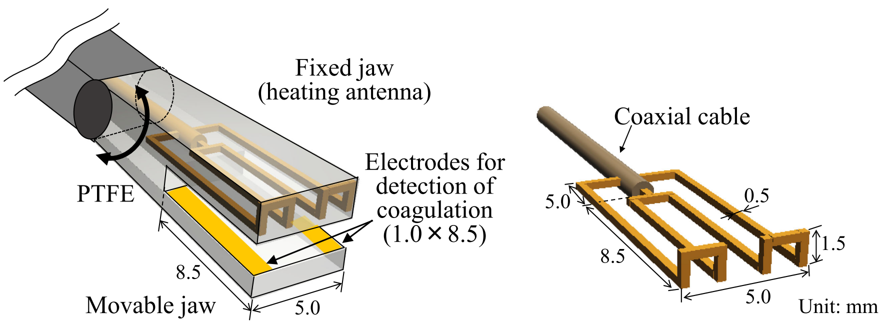
In recent years, studies of electromagnetic wave techniques applicable to the medical field have been investigated [1]. Among these are surgical devices for hemostasis that use microwave energy [2]. These devices can stop bleeding easily and quickly via tissue coagulation. However, while using these devices, excessive or insufficient heating will cause damage to the tissue, resulting in a poor therapeutic effect.

The authors have been studying a method to detect coagulation of biological tissue for use in conjunction with microwave surgical devices. This function will enable efficient treatment and prevent excessive heating of tissue.

The relationship between tissue coagulation and variation of electrical properties has been studied by many authors [3, 4]. This paper proposes the detection of tissue coagulation using a variation in the impedance of the tissue using a microwave surgical device. We thus measured impedance before and after tissue coagulation using the microwave device.

2 Structure of proposed device

The proposed device is forceps-type surgical instrument for heating grasped tissue. The tip of the device consists of a fixed jaw with a heating antenna for tissue coagulation and a movable jaw with a pair of electrodes for detection of tissue coagulation. Fig. 1 shows the proposed heating antenna. This antenna represents an improvement over the antenna described in a previous study [5]. This antenna comprises two loop elements at the tip of a semi-rigid coaxial cable. The shape and size of the proposed antenna was determined based on an impedance of 2.45 GHz, one of the industrial, scientific, and medical (ISM) bands used in Japan.



(a) Overall view of device (b) Heating antenna

Fig. 1. The tip of proposed device

© IEICE 2017
DOI: 10.1587/elex.14.20161223
Received December 9, 2016
Accepted January 4, 2017
Publicized January 20, 2017
Copyedited February 10, 2017

3 Detection of tissue coagulation

3.1 Method

In the device shown in Fig. 1, the completion of tissue coagulation is detected based on the variation of the impedance between the electrodes on the movable jaw. In the low-frequency range below several MHz, electrical properties of biological tissues change remarkably upon coagulation. This variation is caused by the decreased water content of coagulated tissue [6, 7]. Thus, as tissue coagulation proceeds, the water content is reduced, causing a variation in the electrical properties of the tissue.

3.2 Impedance measurement

The impedance between the two electrodes on the movable jaw was measured with an LCR meter (High Frequency LCR Meters 6500P, Wayne Kerr Electronics, Boston, US) before and after the tissue coagulation (Fig. 2). For the measurement, a stick-shaped swine liver is used to simulate human tissue, such as organs. The values of the dielectric properties of swine liver are almost the same as those of the human liver at around 30 °C [8]. Moreover, a human liver has physical properties similar to a human blood vessel [9, 10]. Table I shows the heating condition in this measurement. Fig. 3 shows the surface of the liver tissue after heating and Fig. 4 shows the measured impedance values. These values are averages of 10 measurements. For example, the value of capacitance increased by 90.5% upon coagulation at 300 kHz. In contrast, the value of capacitance decreased by 70.3% at 300 kHz. These values changed significantly due to tissue coagulation. Regarding these measurements, the increase of resistance is caused by damage to the cell structure and resulting loss of water content upon tissue coagulation. The decrease in capacitance is caused by damage to the cell membrane.

To confirm our hypothesis, we observed the state of the cell structure around 60 °C (tissue coagulation temperature) by hematoxylin and eosin (H&E) staining. Fig. 5 shows images of the stained cells (before heating, and at 60 °C, 75 °C, and 100 °C). The white region in these pictures is damaged and shrunken cell tissue. In the images showing heating at 60 °C and 75 °C, the cell tissue is visibly damaged and coalesced by coagulation. Moreover, around 100 °C, the cell membrane completely adhered to peripheral cells. From these images, we confirmed that the cell membrane is damaged by heating tissue to around 60 °C. Thus, the validity of the hypothesis was corroborated by the results obtained by cell staining. These results imply that coagulation of tissue grasped by the device can be detected based on variations of the tissue impedance.

Table I. Heating condition

Shape of tissue	height [mm]	4.0
	depth [mm]	2.0
Heating conditions	Input power [W]	68
	Heating time	10

DOI: 10.1587/elex.14.20161223
Received December 9, 2016
Accepted January 4, 2017
Publicized January 20, 2017
Copyedited February 10, 2017

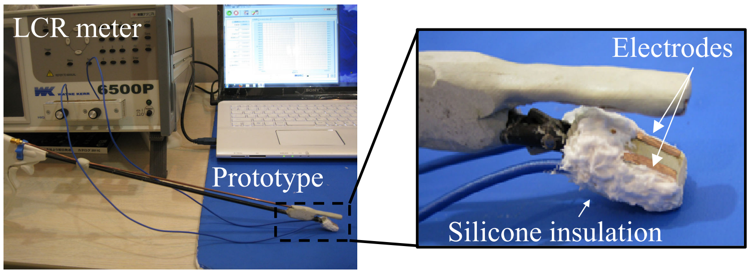


Fig. 2. Measurement system

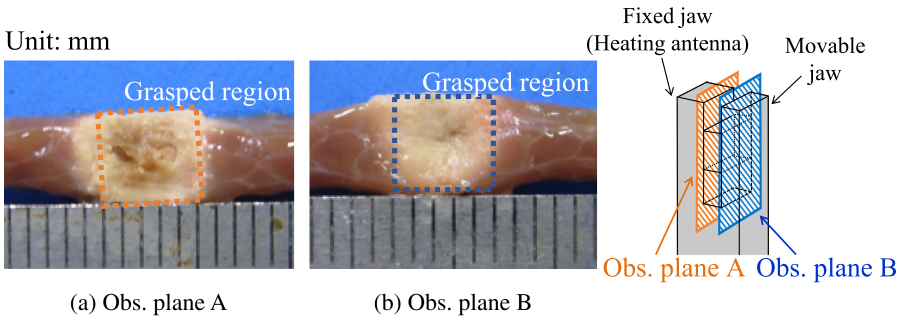


Fig. 3. Results of heating experiment

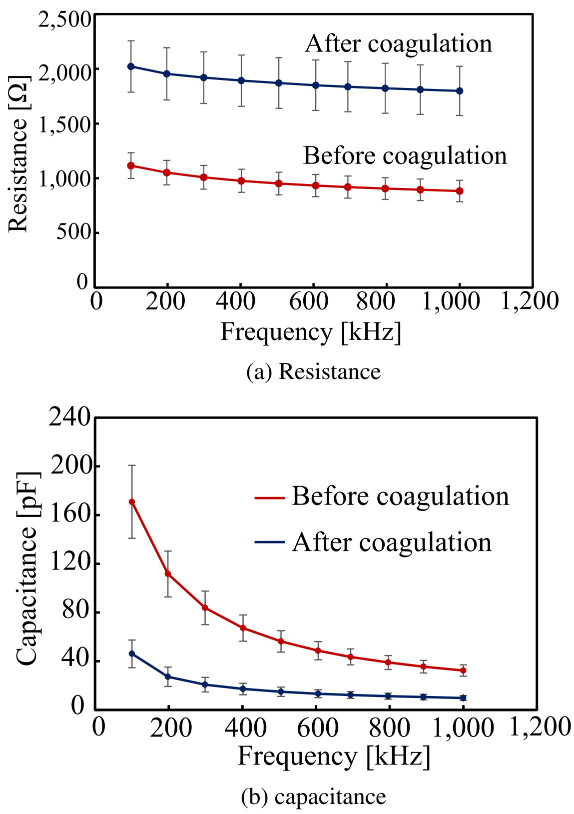


Fig. 4. Results of measurement

4 Electrical circuit for detecting tissue coagulation

A simple bridge circuit was designed to detect tissue coagulation. Fig. 6 shows the circuit diagram. In this circuit, we used only the variation of resistance. Electrodes

DOI: 10.1587/elex.14.20161223
Received December 9, 2016
Accepted January 4, 2017
Publicized January 20, 2017
Copyedited February 10, 2017

ELectronics EXpress
IEICE Electronics Express, Vol.14, No.3, 1–6

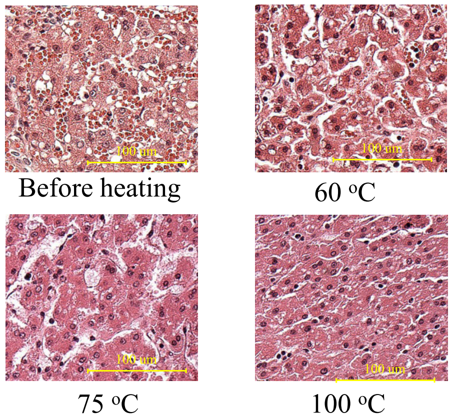


Fig. 5. HE stained liver tissue (swine)

for detection of tissue coagulation are connected to the variable resistance *Rv* in the diagram. This bridge circuit will be out of balance due to variation of impedance *Rv*, and the light-emitting diode (LED) at the center of the circuit will be bright. The power voltage and frequency are 2.2 [Vp-p] and 300 kHz, respectively, and the values of resistance are $R_1 = 1.0$ [kΩ], $R_2 = 1.0$ [kΩ], and $R_3 = 1.5$ [kΩ]. This combination of resistance is an example. The resistance of tissue before heating was 919.1 [Ω]. While operating the circuit, the biological tissue was heated using the microwave surgical device (Fig. 1). After 10 seconds of heating, the LED glimmered and the tissue was coagulated. Moreover, resistance of coagulated tissue was 1751.2 [Ω]. These results show that tissue coagulation can be detected using a simple circuit. Practically, a system directly detecting the variation of *Rv* will be necessary.

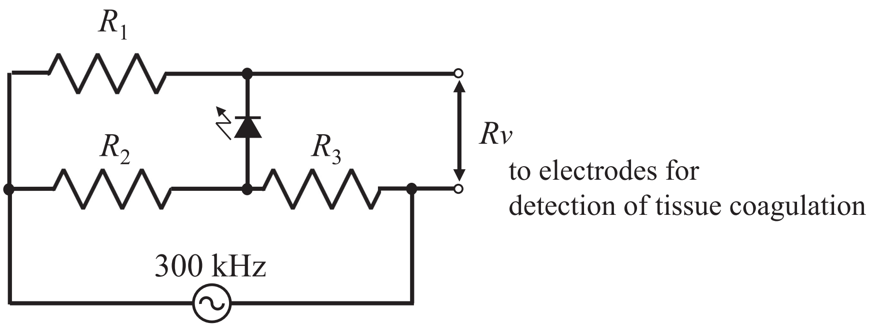


Fig. 6. Detection circuit

5 Conclusion

In this study, the detection of tissue coagulation was examined. For this function, we employed the impedance variation of tissue before and after coagulation. The results of our measurements imply that coagulation of tissue can be detected based on variation in the impedance of the tissue. Moreover, we demonstrated a detection system based on a simple electrical circuit. Thus, tissue coagulation can be detected using a simple circuit. Further studies will focus on the validity of the proposed device as corroborated by *in vivo* experiments.

DOI: 10.1587/elex.14.20161223
Received December 9, 2016
Accepted January 4, 2017
Publicized January 20, 2017
Copyedited February 10, 2017

Acknowledgment

A part of this study has supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (C) 15K06010.

DOI: 10.1587/elex.14.20161223
Received December 9, 2016
Accepted January 4, 2017
Publicized January 20, 2017
Copyedited February 10, 2017