Development of Biological Tissue Coagulation Device using Microwave Energy

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***Abstract*— In recent years, various types of medical applications of microwaves have widely been investigated and reported. In this paper, biological tissue coagulation device, which use the thermal effect of microwave, is introduced. In addition, characteristics of the device are evaluated by numerical calculations and experiments. As a result of investigations, possibilities of surgical treatment by developed device could be confirmed.**

I. Introduction

In recent years, various types of medical applications of microwave have widely been investigated and reported [1]. They are microwave hyperthermia [2],[3], and microwave coagulation therapy (MCT) [4],[5] for treatment of cancer, cardiac catheter ablation for ventricular arrhythmia treatment [6],[7], thermal treatment of benign prostatic hypertrophy (BPH) [8],[9], etc. These all techniques use the thermal effect of biological tissue by the microwave energy. In this study, the authors apply this thermal effect to development of surgical devices.

Generally, electrical scalpel has widely been used for surgical operation. The electrical scalpel uses the radio frequency (RF: from several hundred kHz to several MHz) current and can realize both tissue coagulation and dissection. However, this device has some problems. First, the device requires an external electrode which sometimes causes burn injury around it. Moreover, the RF current may through the unexpected part, and it will cause involuntary muscle movement. In addition, since the device generates excessively high temperature, the biological tissue is carbonized. As a result, fog will be generated. This is one of the serious problems especially in laparoscopic surgery.

By the way, massive bleeding during surgical operation is danger for the patient. Especially, in the laparoscopic surgery cannot be continued under the massive bleeding, because a view of the laparoscope reduces. Therefore, hemostasis is one of the most important treatments. In this study, tissue coagulation device for hemostasis by the microwave energy is introduced (Fig. 1(a)). By using this device, dissection of organ without bleeding can also be realized (Fig. 1 (b)).

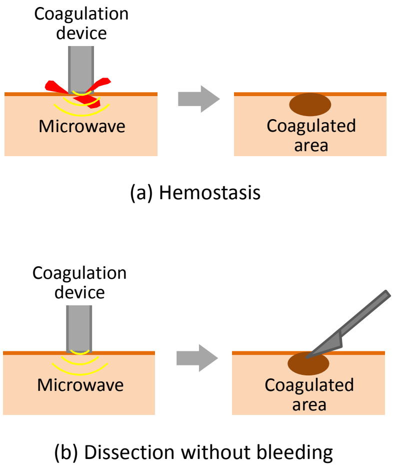

Fig. 1. Microwave tissue coagulation

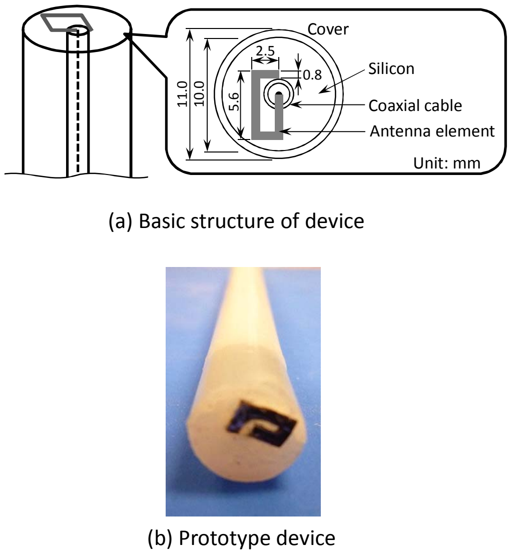

Fig. 2. Microwave tissue coagulation device

This paper describes the structure of developed tissue coagulation device and evaluation of its characteristics by numerical calculation and experiment.

II. Structure of Device

In this study, small loop antenna is employed for the coagulation device. Figure 2 shows the basic structure of the antenna and photograph of a trial manufacture. The antenna is composed of square loop conductor plates whose sizes are 5.6 mm long, 2.5 mm wide. The operating frequency of the antenna is 2.45 GHz that is one of the industrial, scientific and medical (ISM) frequencies.

Figure 3 shows the finite-difference time-domain (FDTD) calculation model. The antenna contacts a muscle tissue, and is fed by a coaxial cable. In addition, the entire antenna is placed in saline solution that assumes bodily fluid.

III. Heating Characteristics

In this study, heating characteristics of the device are evaluated by numerical calculations and experiments.

A. Evaluation by Calculations

Figure 4 shows the calculated specific absorption rate (SAR) distributions around the antenna. The SAR is one of the most important indexes for evaluation of heating characteristics and is heating source inside the biological tissue. Eq. (1) is definition of SAR.

$$\mathrm{SAR} = \frac{\sigma}{\rho} E^2 \quad [\mathrm{W/kg}] \tag{1}$$

where σ is the conductivity of the biological tissue [S/m], ρ is the density of the biological tissue [kg/m^3], and E is the electric field (rms) [V/m].

In Fig. 4, observation planes are xy plane of z =0 and xz plane of y =0. The SAR values are normalized by maximum value. From the results, high SAR regions are observed around the conductor.

Moreover, temperature distribution in muscle tissue is calculated. It can be obtained by solving bioheat transfer equation [10] numerically. Details of the calculation are explained by [11]. In addition, physical properties of muscle tissue are listed in Table I.

Figure 5 shows the calculated temperature distributions in the observation planes which are same as Fig. 4. Here input power and heating time are 40 W and 15 s, respectively. The maximum size of coagulated region (a region more than 60 $^{\circ}$C) is approximately 13 mm in diameter and 6 mm in depth.

TABLE I
PHYSICAL PROPERTIES OF MUSCLE TISSUE

Electrical properties (@2.45 GHz)	
Relative permittivity ε_r	47.0
Conductivity σ [S/m]	2.21
Thermal properties	
Specific heat c [J/kg·K]	3,600
Thermal conductivity κ [W/m·K]	0.50
Density ρ [kg/m^3]	1,020
Blood flow rate F [m^3/kg·s]	8.3×10^{-6}
Initial temperature [$^{\circ}$C]	37.0

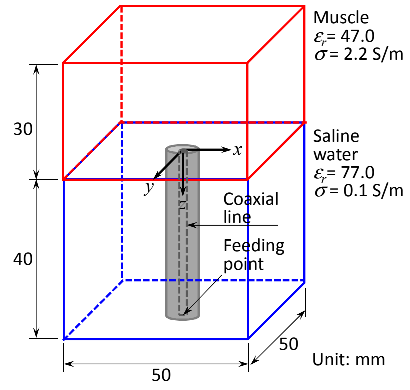

Fig. 3. FDTD calculation model

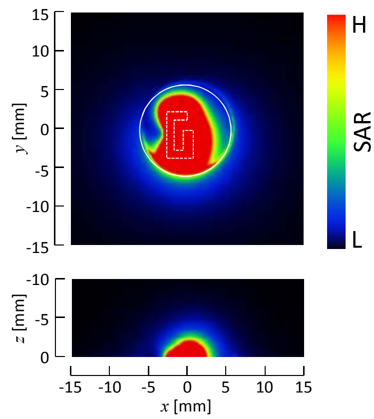

Fig. 4. Calculated SAR distributions

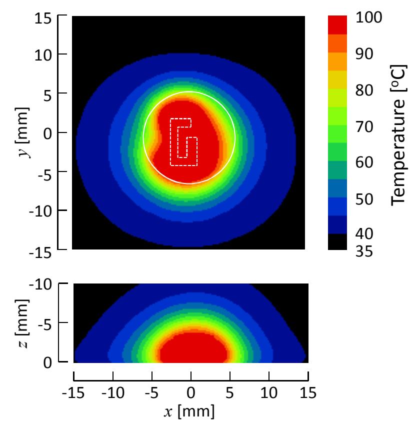

Fig. 5. Calculated Temperature distributions

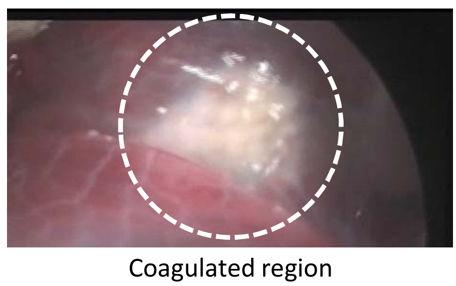

Fig. 6. Tissue coagulation in animal experiment

B. Experiments

Figure 6 is a photograph of the animal experiment by swine. It shows the surface of liver after the coagulation. In this time, input power of the antenna and coagulation time were approximately 40 W and 15 s, respectively. Moreover, the hemostasis can also be confirmed.

IV. CONCLUSION

In this study, the biological tissue coagulation device using the microwave energy was introduced. As a result of numerical calculations, effectiveness of the device could be confirmed. Moreover, the device of trial manufacture could be used for animal experiment. As a further study, prototype devices, which can be used for actual surgical treatment, will be developed.

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