Development of the Coagulation Device by Microwave Energy for Biological Tissue.

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1. Introduction

In recent years, various types of medical applications of electromagnetic waves have widely been investigated and reported. One of them is minimally invasive thermal therapies using microwave. They are microwave coagulation therapy (MCT) [1] and interstitial microwave hyperthermia [2] for medical treatment of cancer, cardiac catheter ablation for ventricular arrhythmia treatment [3], and thermal treatment of benign prostatic hypertrophy (BPH), etc.

The authors have been studying about the microwave antenna for thermal therapy. In particular, we apply the antenna to the biological tissue coagulation. In this technique, tissues are radiated microwave energy, and it heats up the tissue to produce the coagulated region. The biological tissue is coagulated when it is heated around 60°C or above.

Thus we propose the microwave coagulation device for biological tissue that can use various surgeries such as an abdominal operation, a laparoscopic surgery, an underwater surgery, etc. Figure 1 shows a shape of using the device for liver surface. Once the surface is coagulated, it doesn’t get bleeding in cutting. Therefore, this device can stop bleeding as show in figure 2. In this study, we estimated heating characteristics around the antenna by conducting both numerical simulations by using the FDTD (Finite-Difference Time-Domain) method and animal experiment.

Because massive bleeding during surgical operation is danger for the patient, hemostasis is one of the most important treatments. Especially, the laparoscopic surgery cannot be continued when the bleeding is severe because a view of the laparoscope reduces. Generally, the coagulation device for hemostasis is used ultrasonic waves or radio frequency waves. However there devices have some problems. For example, the view is hampered by splash when the ultrasonic wave device is used for a juicy tissue or in the blood. Also this device has possibilities that it heats other than an objective area. On the other hand, the radio frequency wave device threatens to heat excessively and a tissue is carbonised. Moreover, these devices are not able to use in the underwater surgery [4]. Therefore, the coagulation device is required for reliable hemostasis with usability.

Figure 1: Shape of using device for liver surface.
2. Heating Method and Calculation

In this study, we develop a microwave antenna and evaluate heating characteristics of it. This antenna is a planar dipole antenna. Also, the proposed antenna can use underwater by adjusting length of it. The operating frequency of the antenna is 2.45 GHz that is one of the industrial, scientific and medical (ISM) frequencies.

2.1 Structure of the antenna

Figure 3 shows the structure of the proposed antenna. It is composed of 2 conductor plates which sizes are 5 mm long, 6.5 mm wide and 1 mm thick. Also it has a gap of 0.6 mm between plates. A diameter of the coaxial cable for feeding is 2 mm.

2.2 Structure of Calculation Model

Figure 4 shows the FDTD calculation model for the proposed antenna. Figure 3 (a) shows an over all view of the calculation model, figure 3 (b) shows a side view of the model. In this calculation, in order to assume underwater surgery, the region of 8 mm from the top is muscle model (the relative permittivity: ε_r = 47.0, the electrical conductivity: σ = 2.21 S/m), the other region is saline model (ε_r = 77.0, σ = 0.1 S/m). The antenna is placed on the surface of muscle model in saline.
In this section, we describe about the numerical analysis for the heating characteristics around the proposed antenna inside the biological tissue. Using FDTD method, the SAR (Specific Absorption Rate) around the proposed antenna is calculated from following equation
\[
\text{SAR} = \frac{\sigma}{\rho} E^2 \quad [\text{W/kg}]
\]
where \(\sigma\) is the conductivity of the tissue [S/m], \(\rho\) is the density of the tissue [kg/m\(^3\)], and \(E\) is the electric field (rms) [V/m]. The SAR takes a value proportional to the square of the electric field around the antenna and is equivalent to the heating source generated by the electric field in the tissue. The SAR distribution is one of the most important characteristics for the heating.

2.3 Result of Calculation

Figure 5 shows the calculated normalized SAR distributions around the antenna. One of the observation plane is \(x-y\) plane (\(z = 0\)), where is interface between the muscle model and saline model. From this result, the high SAR region around the antenna is observed in figure 5 (a), especially high SAR region is distributed the gap between two conductor plates. Another observation plane is \(x-z\) plane. From the results, the SAR distribution is observed about 5 mm deep in figure 5 (b).

3. Animal Experiment

Figure 6 shows the experimental landscape used in animal experiment using the specific pathogen free pig (SPF pig). This experiment was performed by opening the abdomino. This experiment was performed in accordance with the animal experimental implementation regulation of Chiba University.
On this experiment, the resupine swine was given a general anesthetic. In order to simulate the underwater surgery in the experiment, inside the body cavity was filled with saline. Moreover, saline was flowed by the perfused application, and it was kept the temperature to about 37 degrees. The proposed antenna was placed on the surface of liver in saline. The operating frequency of the antenna is 2.45 GHz, and input power is approximately 50 W. In this experiment, we investigated whether the antenna can coagulate any tissues of liver. Also we verified that the antenna can stop bleeding about 15 seconds when it uses for bleeding wound.

Figure 7 shows the results of the experiment. It shows the surface of liver after the experiment and the chipping that was carved out by the liver. From these results, the surface of liver meeting the antenna was coagulated about 20 mm wide and 2 mm deep. When saline was kept the temperature as much as liver, the proposed antenna could coagulate tissue. In addition, the antenna could stop bleeding when this antenna was used for bleeding wound. Therefore, we confirmed that the proposed antenna is useful as the coagulation device.

![Figure 7: Result of experiment.](image)

4. Conclusion

This paper describes the biological tissue coagulation device by microwave energy. From the results of calculation, the proposed antenna generates the high SAR region around it. Therefore, we indicated a possibility of effectiveness coagulation by the proposed antenna. Also from the results of animal experiment, we confirmed utility of the antenna as a coagulation device. As further study, we will optimize the microwave energy by the antenna.

References