POS1-60

Evaluation of Heating Characteristics of Microwave Thermal Therapy using Biliary Stent fed by Coaxial Probe

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1. Introduction

In recent years, various types of medical applications of microwaves have widely been investigated and reported. In particular, microwave thermal therapies using thin coaxial probes are of a great interest. They are interstitial microwave hyperthermia [1] and microwave coagulation therapy (MCT) [2] for medical treatment of cancer, cardiac catheter ablation for ventricular arrhythmia treatment [3], etc. Up to now, the authors have been studying the intracavitary microwave hyperthermia using a thin coaxial antenna combined with endoscope that is an effective and minimally invasive treatment for deep-seated carcinoma such as bile duct carcinoma.

Hyperthermia is one of the modalities for cancer treatment, utilizing the difference of the thermal sensitivity between tumor and normal tissue. In this treatment, the tumor is heated up to the therapeutic temperature between 42 and 45 degrees centigrade without overheating the surrounding normal tissues. We can enhance the treatment effect of other cancer treatments such as radiotherapy and chemotherapy by using them together with the hyperthermia.

Today, placement of self-expandable metallic stents is the standard of care for patients with malignant objective jaundice caused by bile duct carcinoma if their life expectancy is less than 3 months [4][5]. However, in less than 50% of patients with metallic stents, stent blockage develops within 6 to 8 months [6]. In addition, in previous study, we have known that the metallic stent would shield microwave energy from the antenna inserted into the metallic stent [7]. From the above, newer endoscopic thermal treatment modalities in situation that the stent has implanted in a patient are needed. Therefore, the authors present the endoscopic modality of microwave hyperthermia for bile duct carcinoma. It uses the proposed biliary stent fed by a thin coaxial probe in order to heat efficiently around the biliary stent. Figure 1 shows the proposed treatment scheme. It is possible to be the curative treatment for the patients with stent for life-short bile duct carcinoma. This paper describes the heating characteristics around the proposed biliary stent fed by a coaxial probe by conducting both numerical simulations using the FDTD (Finite-Difference Time-Domain) method and heating experiments using a tissue-equivalent solid phantom.

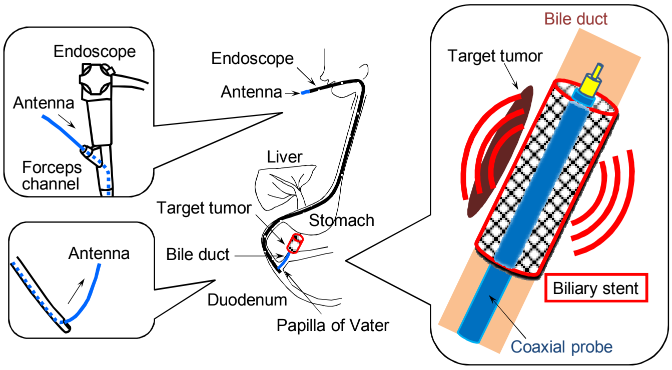


Figure 1: Microwave hyperthermia by use of biliary stent.

2. Heating Method and Calculation

In this study, two types of the biliary stents and an endoscopic probe are introduced. In order to generate a heating region around a biliary stent, a thin coaxial probe is employed, and we optimize the structure of the biliary stent. Here, the operating frequency of the probe is 2.45 GHz, which is one of the industrial, scientific and medical (ISM) frequencies in Japan. This paper describes comparisons of the heating characteristics around the conventional and the proposed metallic stent.

2.1 Structure of Coaxial Probe

Figure 2 shows structure of the coaxial probe. The probe is composed of a thin flexible coaxial cable which can be inserted into the endoscope. The diameter of an outer conductor of the probe is set to be 1.6 mm, and an inner conductor of it sticks away 3mm from the tip of the probe. A feeding point is set at the end of the coaxial cable. The probe is placed at the center of bile duct and is inserted into the stent. The probe passes through the stent end 1 mm and does not contact to the stent. Thus it is fed by electromagnetic coupling.

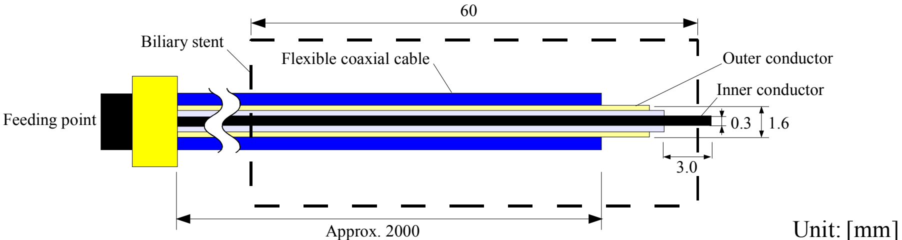


Figure 2: Structure of coaxial probe.

2.2 Structure of the Biliary Stent and Calculation Model

Figure 3 shows the FDTD calculation model for the biliary stent and the coaxial probe. The stent model is placed in the bile duct filled with the bile (relative permittivity: $\varepsilon_r = 67.2$, electrical conductivity: $\sigma = 2.77$ S/m), and the bile duct is in the muscle ($\varepsilon_r = 47.0$, $\sigma = 2.21$ S/m). Moreover, assuming restenosis, the inside of the stent is filled with muscle. There are two types of the biliary stent model. One is the conventional metallic stent. The other is the proposed stent which is composed of a metallic stent and 5 plastic stents of 2 mm in length. Plastic stents are arranged at regular intervals of 8 mm in order to leak microwave energy out from them and heat around the proposed stent extensively. The length and diameter of the stent that was determined taking account of the previous study [5], are 60 mm and 5 mm, respectively. Although the structure of stent is a mesh structure in general, a solid cylindrical structure is used in calculation, because the size of a mesh is small enough in comparison with the wave length.

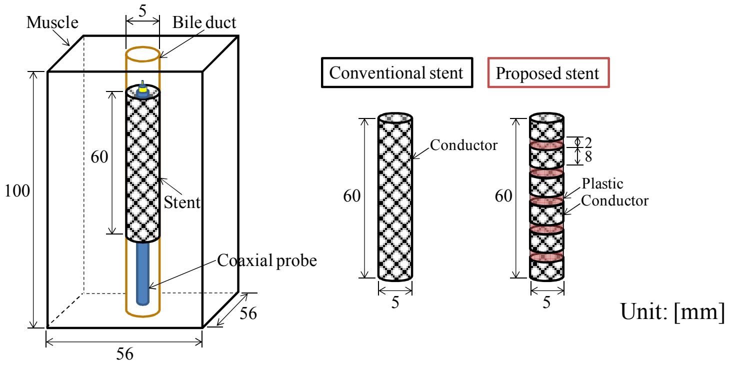


Figure 3: FDTD space for the biliary stent and the probe.

2.3 Parameter for Investigation

In this section, we will describe the method of the numerical analysis for the heating characteristics around the biliary stent inside the biological tissue.

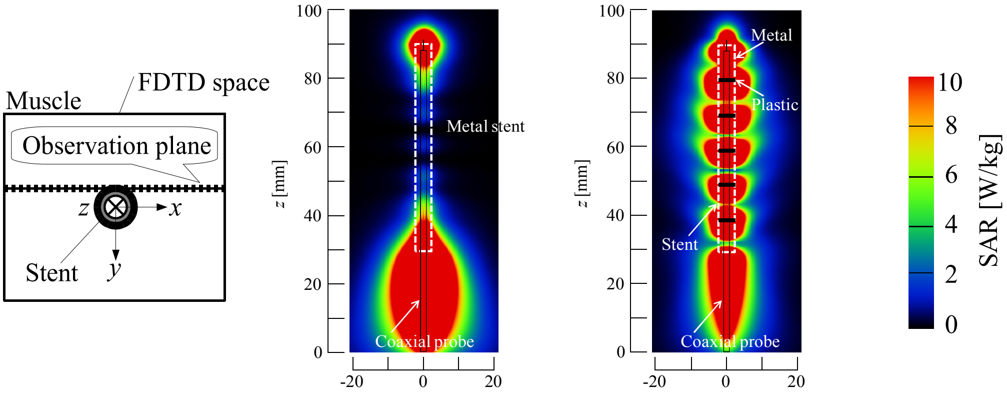
Using FDTD method, the SAR (Specific Absorption Rate) around the biliary stent are calculated from following equation

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

where σ is the conductivity of the tissue [S/m], ρ 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 probe 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.

2.4 Results of Calculation

Figure 4 shows the calculated SAR distributions around the biliary stent. Here, observation plane is x-z plain outside the stent. From these results, the lower SAR region around the central part of the stent ($50 < z < 70$ mm) is observed in figure 4 (a), besides, the higher SAR region around the proposed stent ($30 < z < 90$ mm) is observed figure 4 (b). However, they show that undesirable hot spots from the lower part of the stent to the probe axis are observed respectively.



(a): Conventional stent. (b): Proposed stent.

Figure 4: Calculated SAR distributions.

3. Heating Experiment

3.1 Experimental Setup

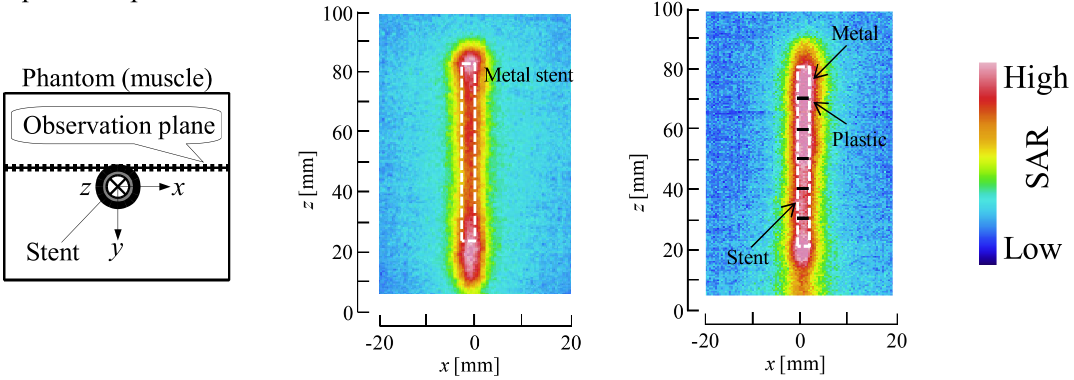
Figure 5 shows the experimental setup. The proposed stent and the conventional metallic stent for trial manufacture are inserted into the muscle-equivalent phantom ($\varepsilon_r = 43.6$, $\sigma = 2.07$ S/m). The diameter of the endoscopic probe is 2.4 mm. The probe is connected to microwave generator and power meter. We measured the temperature rise distributions by an infrared camera and converted them into the SAR distributions [8].

(a) Trial manufactures of stents. (b) Endoscopic probe. (c) Setup.

Figure 5: Experimental setup.

3.2 Results of Experiment

Figure 6 shows the results of the measured SAR distributions around the stent set to be inside of a muscle-equivalent phantom. Figure 6 (a), (b) shows the SAR distribution around the conventional and the proposed metallic stent. From these results, the lower SAR region around the central part of the stent is observed in figure 6 (a). Besides, the higher SAR region around the proposed stent can be observed in figure 6 (b). Although we confirmed that the proposed stent could generate extensively heating regions in the longitudinal direction up to 60 mm, both their SAR distributions are slightly different from results of calculations because of heat loss to the muscle-equivalent phantom.



(a): The conventional stent. (b): The proposed stent.

Figure 6: Measured SAR distributions.

4. Conclusions

In this study, the endoscopic modality of microwave hyperthermia for bile duct carcinoma by use of the proposed biliary stent fed by a thin coaxial probe was described. As the results of investigations, we confirmed that the proposed stent is able to heat around it effectively. Therefore, it is highly possible that it is useful for microwave hyperthermia in situation that it has implanted in a bile duct. As further study, we intend to optimize the structure of the biliary stent in order to control heating regions and do the animal experiment to investigate its usefulness under the blood flow.

Acknowledgments

This work was supported by Grant-in-Aid for Scientific Research(c) 24560397.

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