Evaluation on Performances of Multiple Coaxial-Slot Antenna for Microwave Heating Compatible with Metallic Stent for Bile Duct Carcinoma

Erika Yashima[1], Kazuyuki Saito[2], Yuta Endo[1], and Koichi Ito[2]
[1] Graduate School of Engineering, Chiba University
[2] Center for Frontier Medical Engineering, Chiba University

***Abstract* – In this paper, we describe the microwave intracavitary hyperthermia for bile duct carcinoma after the biliary stent placement. We designed a new type of coaxial-slot antenna which has multiple slots near the tip for effective heating along the stent. Therefore, we evaluate the pattern around the stent which is heated by electromagnetic wave leaking from stent efficiently.**

***Index Terms* — thermal therapy, bile duct carcinoma, biliary stent, microwave.**

I. Introduction

In recent years, hyperthermia using electromagnetic wave has been attracted attention. The 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 between 42 and 45 degrees centigrade because the survival rate of cancer cell decrease in this temperature range.

By the way, the Bile duct carcinoma is difficult to detect in early stages, there are many instances the bile duct become constricted by tumor. Today, placement of self-expandable metallic biliary stents is the standard treatment for patients suffering from bile duct obstruction. However, restenosis of bile duct caused by growth of cancer cell has become a serious problem. In addition, the biliary stent placement is not radical cure, we have yet to discover an effective remedy for bile duct cancer after the biliary stent placement.

Up to now, the authors have been studying the microwave intracavitary hyperthermia for bile duct carcinoma after the biliary stent placement. In this treatment, we are supposing to insert a flexible and thin diameter coaxial-slot antenna using an endoscope into a metallic bilialy stent. After that, the antenna heat tumor around the biliary stent. Fig.1 shows the proposed treatment scheme. When this treatment is established, the bile duct carcinoma can be treated non-invasively. In addition, the microwave intracavitary hyperthermia for bile duct is expected to prevent restenosis of bile duct.

In the previous study, we have known that the temperature in a bile duct could be maintained at 42 degrees centigrade for 30 min without any tissue coagulation by the coaxial slot antenna [1]. However, our previous study shows that it is difficult to obtain effective heating region along the metallic biliary stent, because of the electromagnetic wave shielding effect [2]. From the above, newer endoscopic thermal treatment modalities after the stent placement are needed.

Therefore, in this study, a new type of coaxial-slot antenna which has multiple slots near the tip, is proposed for effective heating along the stent. Moreover, we evaluate the characteristics around the biliary stent which is heated by electromagnetic wave leakimg from stent. First, we describe numerical simulations using the FDTD (Finite-Difference Time-Domain) method. Next, the heating experiment using a tissue-equivalent solid phantom are descried.

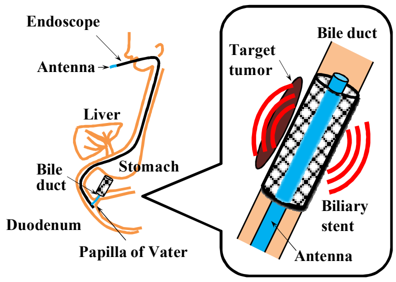


Fig. 1. Microwave hyperthermia for bile duct carcinoma

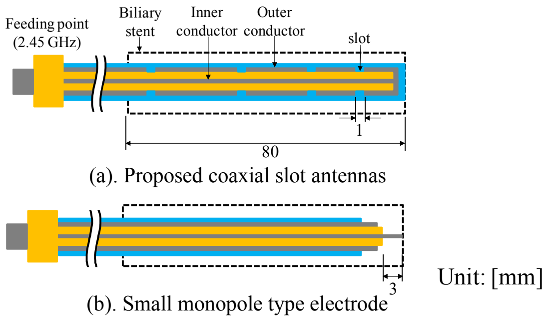
II. Numerical Simulation

We calculated the SAR (Specific Absorption Rate) distribution around the metallic stent and used as an evaluation index of heating effect of microwave. Using FDTD method, the SAR is given by

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

where σ is the conductivity of the tissue [S/m], ρ is the density of the tissue [kg/m³], and E is the electric field [V/m]. The value of SAR is equivalent to the heating source created by the electric field in the biological tissue.

Fig.2 shows the structure of coaxial-slot antenna, which is proposed and small monopole type electrode which is used in a clinical site for tissue ablation. The coaxial-slot antenna and the small monopole type electrode consist of a flexible coaxial cable. The coaxial-slot antenna has four slots, and a short circuit occurs between the inner conductor and the outer conductor of the tip of the antenna. The slot is cut out the outer conductor of the coaxial cable 1mm in width. On the other hand, an inner conductor of the small monopole type electrode sticks away 3 mm from the tip of the cable.



(a). Proposed coaxial slot antennas

(b). Small monopole type electrode

Fig. 2. Structure of the antennas

Fig. 3 shows the FDTD calculation model for the coaxial-slot antenna and the biliary stent. The biliary 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). The coaxial-slot antenna model is inserted into the biliary stent model that has a diameter of 8 mm. Here, the operating frequency of the antenna is 2.45 GHz. The structure of biliary stent model consists of jagged parts which were made with fine box cells. The jagged parts are connected at 1mm distances. We use the biliary stent available on the market as reference for the biliary stent model.

Fig. 4 shows the calculated SAR distribution is heated by proposed coaxial slot antenna. Here, observation plane is *x-z* plane outside the biliary stent. Fig. 5 shows calculated SAR profiles are heated by the proposed antenna and the small monopole type electrode. In the SAR distribution, the higher SAR region around stent ($20 < z < 100$ mm) is observed. From the SAR profiles, the small monopole type electrode heat around the tip of the cable ($80 < z < 100$ mm). Besides, the proposed coaxial-slot antenna heat around the stent ($20 < z < 100$ mm).

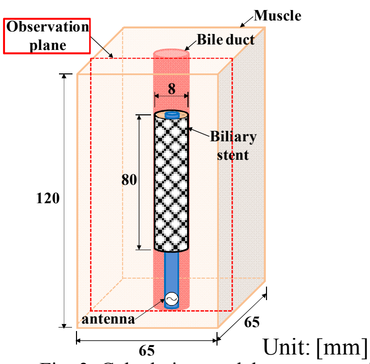


Fig. 3. Calculation model

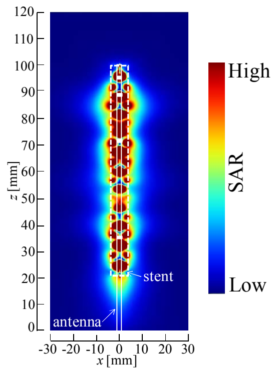


Fig. 4. SAR distribution

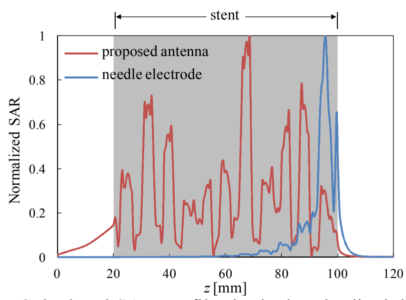


Fig. 5. Calculated SAR profiles in the longitudinal direction

III. Validation by Experiment

Fig. 6 shows the experimental system for heating experiment. The coaxial-slot antenna is connected to microwave generator and power meter. The input power and the radiation time for the antenna are set 30.8 W and 30 s. We measured the temperature distribution by an infrared camera and converted then into the SAR distributions [3].

Fig. 7 shows the measured SAR distribution around stent which is heated by the proposed coaxial-slot antenna, observation plane is outside the biliaty stent. In this result, the higher SAR distribution is observed in the central part of stent ($50 < z < 80$ mm) and the both ends of the stent ($20 < z$ <40 mm, $90 < z$ <100 mm). Tendency of heating region in the experimental result corresponded with the analytical result, therefore we confirmed the validity of numerical simulation.

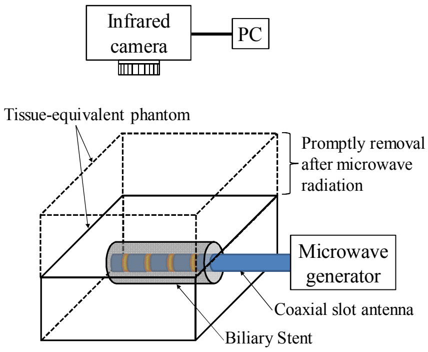


Fig.6. Experimental system

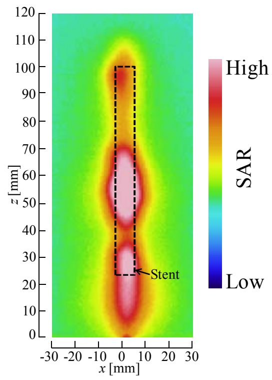


Fig. 7. SAR distribution

IV. Conclusion

In this study, the microwave intracavitary hyperthermia for bile duct carcinoma after the biliary stent placement using proposed coaxial-slot antenna was described. As the results of investigations, we confirmed that the proposed coaxial-slot antenna is able to heat around metallic biliary stent effectively. Therefore, it is highly possible that it is useful for microwave hyperthermia in situation that using proposed antenna. As further study, in order to heat around the stent uniformly, we intend to optimize the structure of the coaxial-slot antenna.

Acknowledgment

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

References

[1] K. Tsubouchi et al., "Experimental Evaluation of Microwave Antenna for Thermal Treatment of Bile Duct Carcinoma," *Thermal Medicine*, vol. 26, no. 4, pp. 121-130, Des. 2010.

[2] K. Saito, K. Tsubouchi, M. Takahashi, K. Ito, "Practical Evaluations on Heating Characteristics of Thin Microwave Antenna for Intracavitary Heating," *32nd Annual International Conference of the IEEE EMBS 2010*, pp.2755-2758, Sep. 2010.

[3] Y. Okano, K. Ito, Ichirou Ida, M. Takahashi, "The SAR evaluation method by a combination of thermographic experiments and biological tissue-equivalent phantoms," *IEEE Transaction Microwave Theory and Techniques*, vol.48, no.11, pp.2094-2103, 2000.