HEATING PATTERNS OF COAXIAL-DIPOLE ANTENNAS FOR MICROWAVE COAGULATION THERAPY

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1. Introduction

In recent years, various types of applications of electromagnetic techniques to microwave thermal therapy have been developed[1],[2]. The authors have been studying the thin coaxial antennas for the minimally invasive microwave thermal therapy. In particular, we have studied the antennas for the microwave coagulation therapy (MCT).

The MCT has been used mainly for the treatment of hepatocellular carcinoma[3]. In the treatment, the thin antenna is inserted into the tumor and the microwave energy heats up the tumor to produce the coagulated region including the cancer cells. We have to heat the cancer cells up to at least 60 °C above which the cells are coagulated.

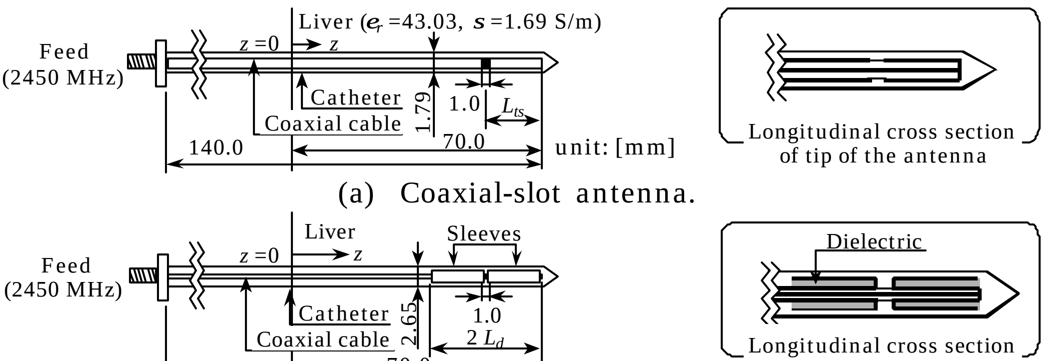
At present, there are two problems to be improved for the conventional MCT antennas. First, length of the coagulated region becomes long in the antenna insertion direction. Second, the size of the coagulated region is insufficient in the perpendicular direction of the antenna axis. In order to solve the first problem, we introduce the coaxial-dipole antenna. Moreover, we introduce the array applicator composed of two coaxial-dipole antennas in order to solve the second problem.

2. Thin coaxial antennas for the interstitial heating

The authors have been studying the coaxial-slot antenna[4] for the interstitial heating. Figure 1(a) shows the structure of the coaxial-slot antenna. A ring slot is cut on the outer conductor of a thin coaxial cable and the tip of the cable is short-circuited.

Let's introduce the coaxial-dipole antenna[5] to obtain the localized heating pattern only around the tip of the antenna. Figure 1(b) shows the structure of the coaxial-dipole antenna. The antenna has two sleeves on both sides of the slot.

The operating frequency is set to 2450 MHz for each antenna because the frequency is used for the conventional MCT.



(a) Coaxial-slot antenna.

(b) Coaxial-dipole antenna.

Fig. 1 Thin coaxial antennas for the interstitial heating.

3. FDTD analysis

3.1 FDTD analytical model and experimental validation

In this section, we investigated the heating characteristics of the coaxial-dipole antenna by the FDTD method. Figure 2 shows the FDTD analytical model[6]. The cross section of the antenna was treated as a square. We conducted the calculation only for the quadrant I in x–y plane: the magnetic wall boundary conditions were applied to the x–z (y = 0) and y–z (x =0) planes. We employed the SAR distributions to evaluate the heating ability of the antenna. The SAR indicates the heat generated by the electric field in the human body, and is given by Eq. (1):

$$\mathrm{SAR} = \frac{s}{r} E^2 \qquad [\mathrm{W/kg}] \qquad (1)$$

where s : conductivity of the tissue [S/m], r: density of the tissue [kg/m^3] and E: electric field (rms) [V/m].

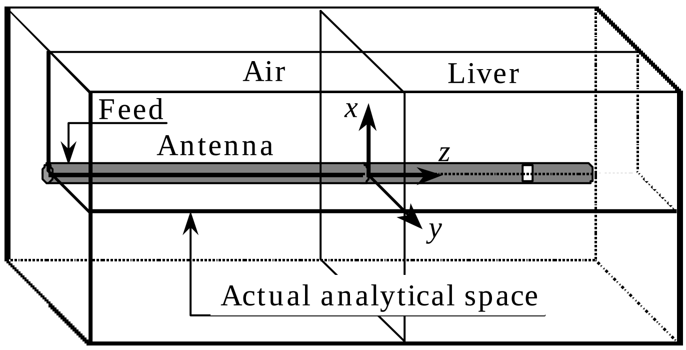


Fig. 2 FDTD analytical model.

Figure 3 shows the calculated and measured SAR profiles of the coaxial-slot antenna. Here, L_{ts} was set to 10 mm. We measured the SAR profile along the antenna axis (z axis) by using the thermographic method[7],[8]. Each result is the profile of the longitudinal direction of the antenna at the distance of 3 mm away from the center of the antenna. From the results, we may say that good agreement is observed between the calculated and the measured results.

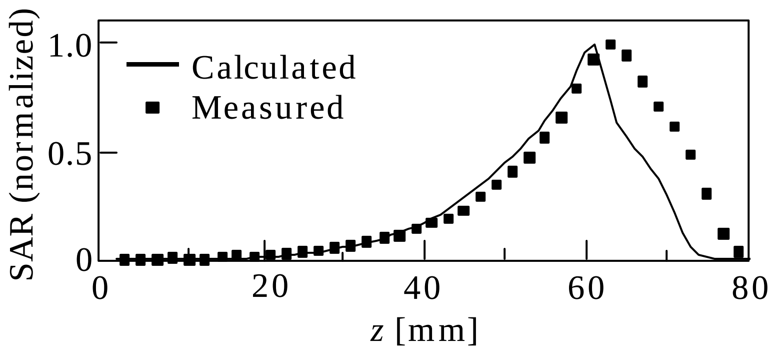


Fig. 3 Validation of analytical model.

3.2 Analytical results

Figure 4 shows the calculated SAR profiles of the coaxial-slot antenna and the coaxial-dipole antenna. Here, L_{ts} and 2 L_d were set to 10 mm and 20 mm, respectively. The results are the profiles of the longitudinal direction of the antenna at the distance of 3 mm away from the center of the antenna. By comparing the calculated results of the coaxial-dipole antenna and the coaxial-slot antenna, we can observe that the more localized SAR profile at the tip of the antenna is achieved in the coaxial-dipole antenna.

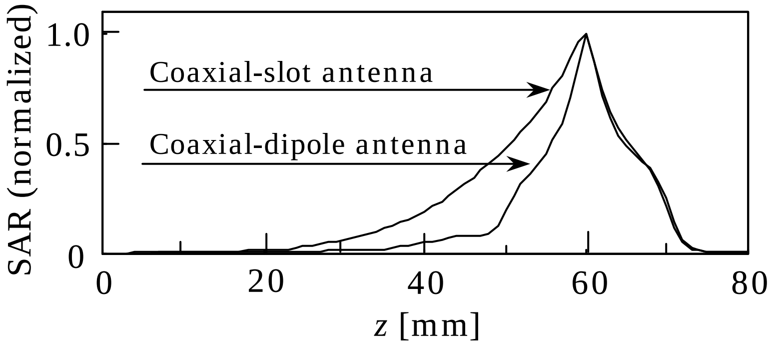


Fig. 4 FDTD analytical result.

4. Coagulation experiment

4.1 Experimental set up

In the present section, we also confirmed the effectiveness of the coaxial-dipole antenna by the coagulation experiment. Figure 5 shows the experimental set up of the coagulation experiment. First, we preheated the liver of pig about 30 °C. Next, we placed the antenna between two liver blocks. After heating, we observed the coagulated region on the surface of one piece of the liver block.

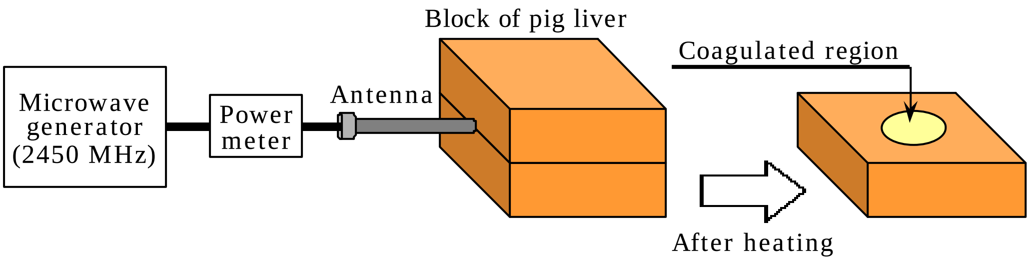
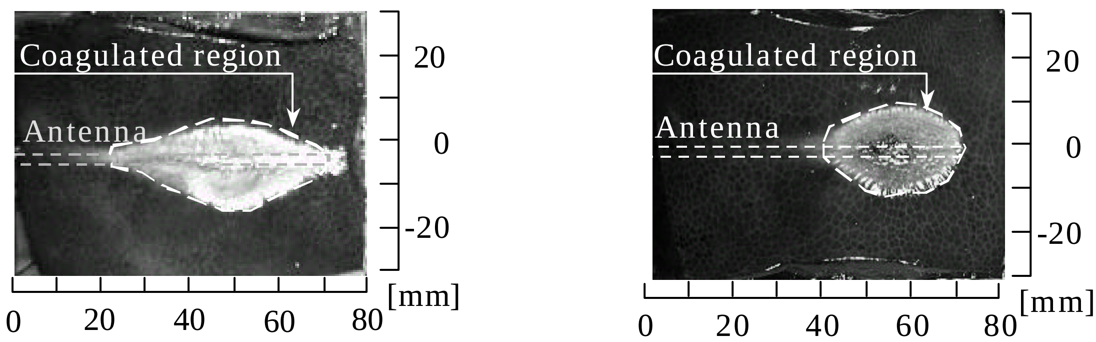


Fig. 5 Experimental setup of coagulation experiment.

4.2 Experimental results

Figure 6 shows the results of coagulation experiment in the observation plane. In the experiments, the heating time was set to 90 s. From the Fig. 6 (a), we can recognize that the coagulated region becomes long in the antenna insertion direction. On the other hand, in the Fig. 6 (b), it is clear that the coagulated region exists only around the tip of the antenna. By comparing the Fig. 6 (a) and (b), we can observe that the length of the coagulated region (antenna insertion direction) of the coaxial-dipole antenna was approximately 50 % of that of the coaxial-slot antenna. This result means that the coaxial-dipole antenna is very useful for localized heating.



(Net input power: 43.6 W)
(a) Coaxial-slot antenna.
(Net input power: 43.1 W)
(b) Coaxial-dipole antenna.
Fig. 6 Results of coagulation experiment.

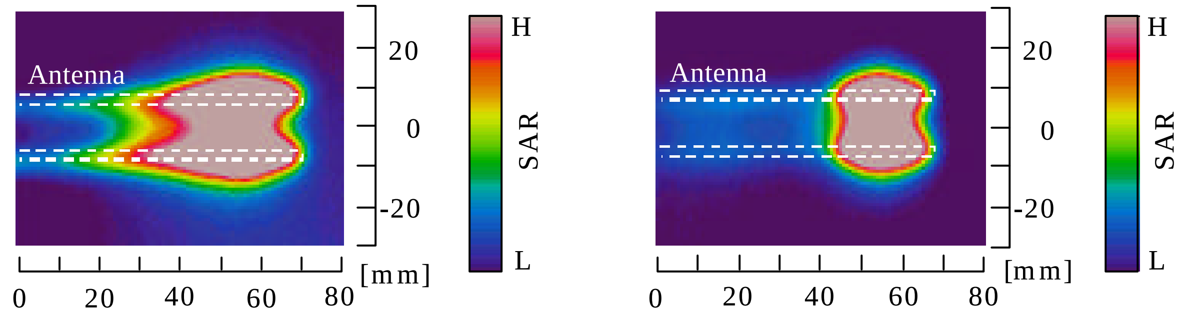
5. Localized heating in the array applicator

5.1 Array applicator composed of two coaxial-dipole antennas

In this section, in order to expand the coagulated region in the perpendicular direction of the antenna while keeping the localized heating only around the tip of the antenna, we investigated the array applicator composed of two coaxial-dipole antennas. Here, we employed the array applicator whose array spacing is 15 mm. We inserted the antenna into a liver-equivalent phantom and measured the SAR distribution by the thermographic method. We considered the SAR distribution in the observation plane that is touched to the two antennas and is parallel to the two antennas.

5.2 Experimental results

Figure 7 shows the measured SAR distributions of two-antennas array applicators in the observation plane. From the Fig. 7 (a), we can recognize that the high SAR region becomes long in the antenna insertion direction. On the other hand, in the Fig. 7 (b), it is clear that the high SAR region exists only around the tip of the antennas. From these results, we may say that the array applicator composed of the coaxial-dipole antennas has possivility of expanding the coagulated region, keeping the localized heating only around the tip of the antennas.



(Net input power: 57.7 W, Heating time: 10 s)
(a) Coaxial-slot antennas.

(Net input power: 55.7 W, Heating time: 10 s)
(b) Coaxial-dipole antennas.

Fig. 7 Measured SAR distributions of two-antennas array applicator.

6. Conclusions

It was clear from our FDTD analysis and coagulation experiment that the coaxial-dipole antenna can realize the localized heating only around the tip. Moreover, we also confirmed the characteristics of localized heating in the array applicator composed of two coaxial-dipole antennas, by the thermographic method. As a further study, we should optimize the structural parameters of the coaxial-dipole antenna. In particular, we should realize a thinner coaxial-dipole antenna. Moreover, we are going to reveal the effectiveness of the coaxial-dipole antenna by conducting the animal experiment.

Acknowledgement

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