HEATING OF NECK TUMOR BASED ON MRI DATA BY USING A COAXIAL-SLOT ANTENNA

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1. Introduction

In recent few decades, various types of medical applications of microwaves have widely been investigated and reported [1]. In particular, minimally invasive microwave thermal therapies using thin applicators are of great interest. They are interstitial microwave hyperthermia and microwave coagulation therapy (MCT) for medical treatment of cancer, cardiac catheter ablation for ventricular arrhythmia treatment, thermal treatment of BPH (Benign Prostatic Hypertrophy), and so on. The authors have been studying the thin coaxial antennas for the interstitial microwave hyperthermia that is one of the minimally invasive microwave thermal therapies.

Hyperthermia is one of the modalities for cancer treatment, utilizing the difference of the thermal sensitivity between tumor and normal tissue. In this treatment, tumor or target cancer cell is heated up to the therapeutic temperature between 42 and 45 °C without overheating surrounding normal tissues. Particularly, combination of the hyperthermia and the radiation therapy is effective for treatment of unradiocurable tumor [2].

The authors have been studying the heating characteristics of the antennas for the hyperthermic treatment under the assumption that the human body is a homogeneous medium. In this paper, the heating characteristics of thin coaxial antenna are analyzed in complicated media that is based on the MRI (Magnetic Resonance Imaging) data including a neck tumor.

2. Coaxial-slot antenna

We used a coaxial-slot antenna [3] as the thin coaxial antennas for the interstitial heating. Figure 1 shows the basic structure of the considered coaxial-slot antenna. This antenna is made of a thin semirigid coaxial cable, whose outer diameter is approximately 1.0 mm. The tip of the cable is short-circuited and several ring slots are cut on the outer conductor. In this paper study, we set two slots on the antenna, because the heating pattern of the antenna can be controlled independently of the antenna insertion depth. Moreover, we have already confirmed the best combination of the position of each slot [4]. Here, the length from the tip to the center of the slot close to the feed point is 20 mm, and the length from the tip to the center of the slot close to the tip is 10 mm. The antenna was inserted into a catheter made of PTFE for hygiene. The operating frequency is 2,450 MHz, which is one of the ISM (Industrial, Scientific, and Medical) frequencies.

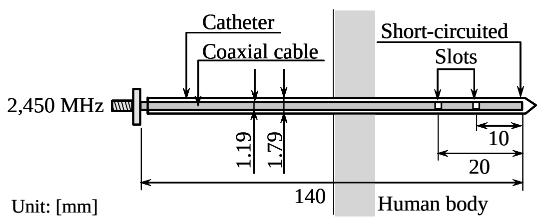


Fig. 1 Coaxial-slot antenna.

3. Calculation model

Figure 2 (a) shows one of the tomograms including a tumor which is obtained by the MRI. The size of the tumor is the maximum in this horizontal plane and is approximately 38×25 mm^2 here. We defined the calculating region as Fig. 2 (b) by using Fig. 2 (a) and several tomograms at other horizontal positions. This region is placed at the jaw portion and includes a target neck tumor, two bones, and a respiratory tract. Figure 2 (c) shows a three-dimensional calculation model and Table 1 shows the physical and biological properties of each medium [5]-[7]. In this study, we assumed that single coaxial-slot antenna with two slots is employed for the heating. The calculation model of the coaxial-slot antenna is the same as [8].

Figure 3 shows the flowchart of computer simulation for calculating the temperature distribution around the antenna inside the tissue. First, we analyze the electric field around the antenna by the FDTD method and calculate the SAR (Specific Absorption Rate) from the following equation:

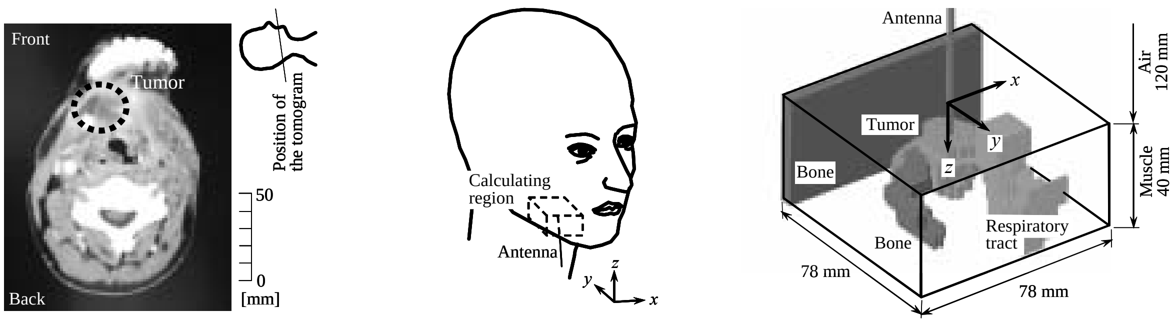
$$\mathrm{SAR} = \frac{\sigma}{\rho} E^2 \qquad \text{[W/kg]} \tag{1}$$

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 generated around the antennas and is equivalent to the heating source created by the electric field in the tissue. The SAR distribution is one of the most important characteristics of antennas for heating.

Next, we calculate the temperature distribution around the antenna. In order to obtain the temperature distribution in the tissue, we numerically analyze the bioheat transfer equation [9] including the obtained SAR values by using the FDM (Finite Difference Method). The bioheat transfer equation is given by

$$\rho c \frac{\partial T}{\partial t} = \kappa \nabla^2 T - \rho\rho_b c_b F \left(T - T_b\right) + \rho \cdot \mathrm{SAR} \tag{2}$$

where T is the temperature [°C], t is the time [s], ρ is the density [kg/m^3], c is the specific heat [J/kg·K], κ is the thermal conductivity [W/m·K], ρ_b is the density of the blood [kg/m^3], c_b is the specific heat of the blood [J/kg·K], T_b is the temperature of the blood [°C], and F is the blood flow rate [m^3/kg·s].



(a) MRI data. (b) Calculating region. (c) Calculation model.

Fig. 2 Computation model.

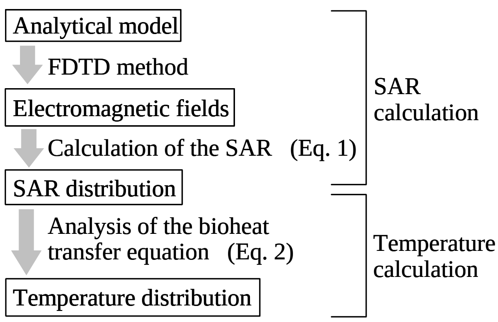


Fig. 3 Procedure for calculation.

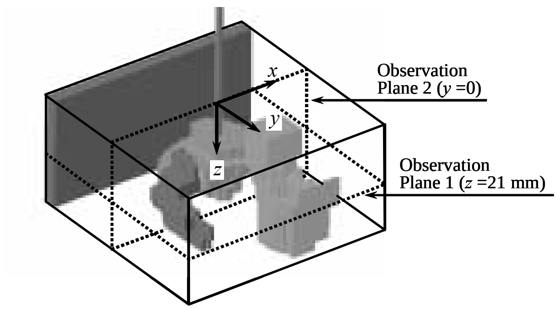
Table 1 Physical and biological properties of tissue.

Electrical properties (2,450 MHz)				
	Muscle	Bone	Tumor	
Relative permittivity ε_r	47.0	18.5	38.0	
Conductivity σ [S/m]	2.21	0.81	1.15	
Thermal properties				
	Muscle	Bone	Blood	Tumor
Specific heat c [J/kg·K]	3,500	1,300	c_b=3,960	3,900
Thermal conductivity κ [W/m·K]	0.60	0.44	-	0.57
Density ρ [kg/m^3]	1,020	1,790	ρ_b=1,060	1,040
Blood flow				
	Muscle	Bone	Tumor	
			Center	Periphery
Blood flow rate F ×10^{-6} [m^3/kg·s]	8.30	0.42	0.0	1.67

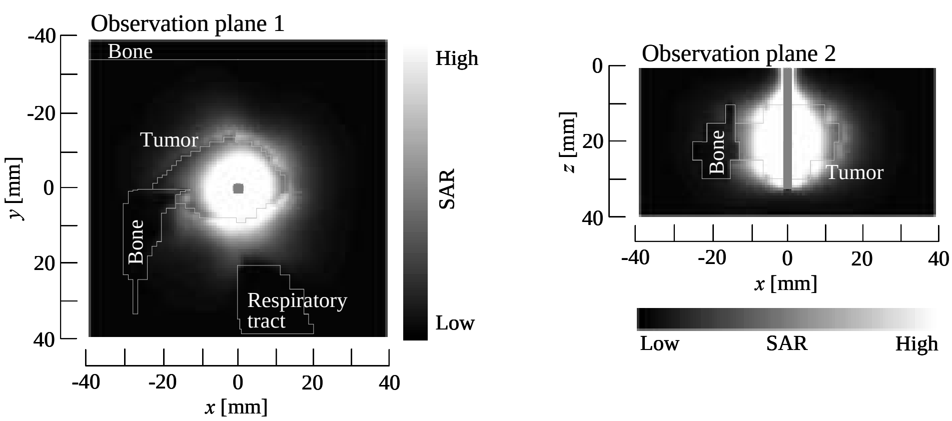
4. Calculated results

Figure 4 shows the calculated SAR distributions around the coaxial-slot antenna. The observation planes of the distribution are defined in Fig. 4 (a). The size of the tumor in the *x*-*y* plane and the *x*-*z* plane is maximum in these observation planes. The distributions are shown in Fig. 4 (b). From Fig. 4 (b), we can observe the high SAR region not only the area close to the antenna (x =0, y =0) but also the boundary of the tumor. However, the value of the SAR is low in the region of the bone adhered to the tumor because of low electric conductivity.

Figure 5 shows the calculated temperature distributions. Here, the observation plane is the same as Fig. 4 (a). Here, the initial temperature of each medium, the heating time and the net input power of the antenna (= input power – reflection power) are 37.0 °C, 300 s and 10.0 W, respectively. From Fig. 5, we can find the relatively uniform heating region though the SAR distributions are not uniform especially around the boundary of the tumor. Moreover, we may say that the region of the tumor is almost covered by the therapeutic temperature (42 °C or more).



(a) Observation planes.



(b) Calculated SAR distribution.

Fig. 4 SAR distributions.

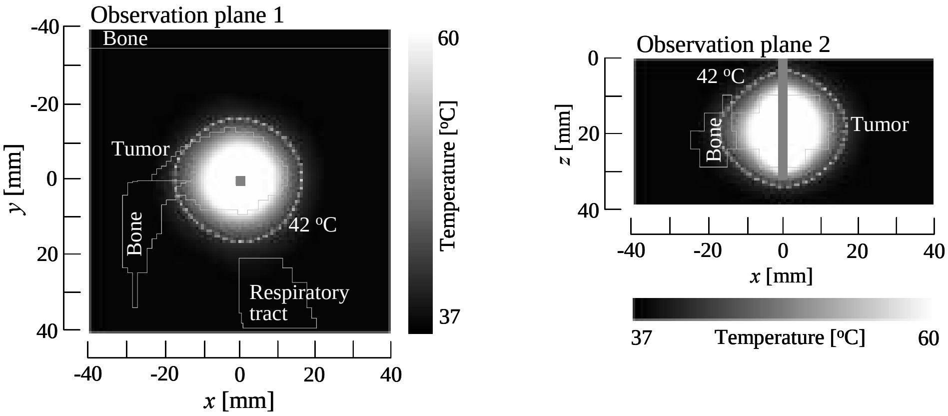


Fig. 5 Temperature distributions.

5. Conclusions

In this paper, we calculated the heating pattern around the coaxial-slot antenna inserted into a neck tumor based on the MRI data. First, we introduced the coaxial-slot antenna and explained the calculation model reconstructed from the tomograms. Next, we showed the calculated results of the SAR and the temperature distributions. As a result, we could confirm the possibility of the treatment for the actual neck tumor. As a further study, we are going to apply our results to the treatment.

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