A8 – 2

Properties and Applications of Biological Tissue-Equivalent Phantom

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INTRODUCTION

Recently, the estimation of interaction between a human body and electromagnetic waves is more necessary for the improvement of antenna performance for mobile communication devices. In the field of medicine, the applications of electromagnetic waves have been studied for treatments, for example, hyperthermia, microwave coagulation therapy (MCT [1]), microwave catheter ablation, and so on.

In general, the electromagnetic wave effects cannot be measured inside the human body. Therefore, a lot of biological tissue-equivalent phantoms have been proposed as human tissue models, which have the same electrical properties as the human body. By using the phantom, it is possible to estimate the interaction between the human body and electromagnetic waves. Specific absorption rate (SAR) is employed as the estimation parameter. The SAR is the absorbed power per unit mass in the tissue and is given by Eq. (1).

$$\mathrm{SAR} = \frac{\sigma E^2}{\rho} \ [\mathrm{W/Kg}] \qquad (1)$$

where E is the amplitude of electric field (rms) [V/m],

σ is the electric conductivity of tissue [S/m],

ρ is the density of tissue [kg/m^3].

This paper presents the properties of the biological tissue-equivalent phantom. Moreover, we show the SAR distribution in the phantom, which is generated by the antenna for the MCT. In particular, we treat the liver-equivalent phantom because the MCT is mainly used in the cancer treatment of the liver.

PHANTOM

The biological tissue-equivalent phantom [2] has the same electrical properties as the high water content tissue (e.g. muscle, skin, and so on). This phantom is made from deionized water, agar, NaCl, dehydroacetic acid sodium salt, TX-151 (Super stuff) and polyethylene powder. The agar maintains the shape of the phantom by itself. The quantity of NaCl decides the conductivity. Dehydroacetic acid sodium salt is the preservative. The polyethylene powder controls the relative permittivity of the phantom.

The features of the biological tissue-equivalent phantom are as follows.

- It is easy to obtain materials and no special equipment is necessary to making it.
- It has almost the same relative permittivity and conductivity as biological tissue in microwave region.
- It is easy to cut and manufacture arbitrary sharp because of solid.
- It is enough stable so as to keep the properties for more than a month at room temperature.

Each researcher needs different values as the electrical properties of the biological tissue. Hence, it is desirable that the electrical properties of the phantom are easily controllable.

It is possible to adjust the electrical properties by changing the composition of the phantom. In this study, we changed only the quantities of NaCl and polyethylene powder. The quantities of deionized water, agar and dehydroacetic acid sodium salt were no changed. The quantity of TX-151 is dependent on that of polyethylene powder (PEP). The relation between the quantities of TX-151 and PEP is given by Eq. (2).

$$(TX\text{-}151)=0.0001(PEP)^2-0.213(PEP)+143.79 \text{ [g]} \qquad (2)$$

Figure 1 gives the relative permittivity and conductivity for various quantities of NaCl and polyethylene powder at 2.45GHz. The conductivity is affected by the quantities of NaCl and polyethylene powder. However, the relative permittivity is affected only by the quantity of polyethylene powder.

In the liver tissue, the relative permittivity is 43.03 and the conductivity is 1.69 S/m at 2.45GHz used for the MCT [3]. Table 1 shows the composition of the liver-equivalent phantom.

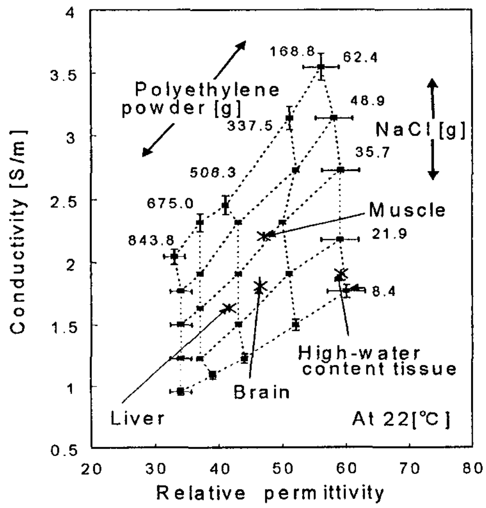

Fig. 1 Adjustment of electrical properties of the phantom.

Table 1 Composition of liver-equivalent phantom

Deionized water	3375 [g]
Agar	104.6 [g]
NaCl	28.2 [g]
Dehydroacetic acid sodium salt	2.0 [g]
TX-151	46.1 [g]
Polyethylene powder	668.5 [g]

THERMOGRAPHIC METHOD

The thermographic method is one of the measurement methods for estimation of the SAR, where the solid phantom is used. Figure 2 shows the measurement systems of the thermographic method. In this method, the SAR is measured as the temperature rise in a cross section of the split phantom by using an infrared camera. The temperature rise is caused by radiation of the microwave for the solid phantom. If the heating diffusion is negligibly small, the SAR at an arbitrary point is directly given by Eq. (3).

$$\mathrm{SAR} = c\frac{\Delta T}{\Delta t}\ \text{[W/Kg]} \qquad (3)$$

where c is the specific heat of phantom material [J/kg·K],
ΔT is the temperature rise at the point [K],
Δt is the radiation time [s].

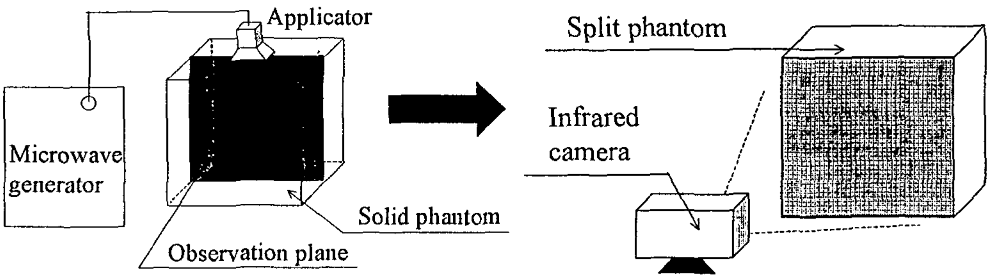

Fig. 2 Thermographic method.

MICROWAVE COAGULATION THERAPY

The MCT has been mainly used for the treatment of small hepato-cellular carcinoma. In this treatment, a thin microwave antenna is inserted into the tumor, and the microwave energy heats the tumor to produce the coagulated region including the cancer cells. We have to heat the cancer cell up to at least 60 ℃ or above, where the cells are coagulated. This treatment gives relief to patients in comparison with the surgery.

In this paper, we use the coaxial-slot antenna (Fig. 3) for the MCT. This antenna is composed of a thin coaxial cable whose outer diameter is approximately 1.0 mm. The tip of the cable is short-circuited and a ring slot is cut on the outer conductor. The antenna is embedded into a catheter for medical safety.

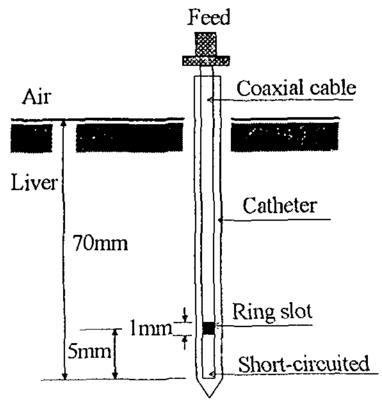

Fig. 3 Basic structure of the coaxial-slot antenna.

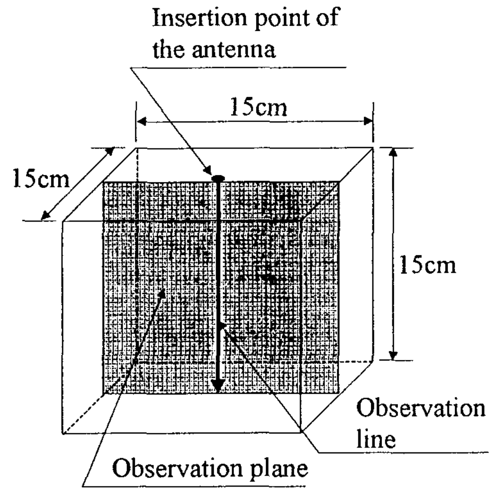

Fig. 4 Observation plane and line.

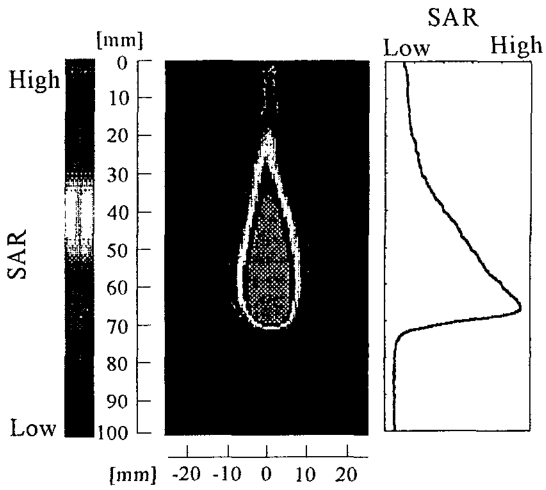

Fig. 5 Measured SAR .

EXAMPLE OF THE SAR

In this section, we describe the measurement conditions of the SAR in the liver-equivalent phantom and show an example of the SAR distribution. We inserted the antenna at the center of the phantom shown in Fig. 4, and radiated the microwave energy into the phantom. The input power was 25 W and the heating time was 20 s to minimize the heat diffusion.

The SAR distribution at the observation plane and the observation line shown in Fig. 4 were obtained as Fig. 5. Figure 5 describes that the SAR distribution in biological tissue could be estimated without using the actual human body.

CONCLUSION

The properties of the solid biological tissue-equivalent phantom for the microwave were reported. Moreover, we showed the SAR distribution in the phantom for the medical use. As a further study, we are going to improve the antennas for the MCT by use of this phantom and the thermographic method.

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