TISSUE-EQUIVALENT LIQUID FOR EXPERIMENTAL ESTIMATION OF LOCAL SAR CAUSED BY HAND-HELD AMATEUR RADIO COMMUNICATION DEVICES

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1 Introduction

The growing use of wireless communications has led to concerns about the health effects of exposure to electromagnetic waves from wireless communication devices. In 1997, the Telecommunications Technology Council of the Ministry of Posts and Telecommunications in Japan revised its "Radio-Radiation Protection Guidelines" [1]. The localized exposure to radiofrequency fields (100 kHz to 3 GHz) is now limited to be less than the "partial-body absorption guidelines" in terms of the locally averaged specific absorption rate (SAR).

Methods for estimating the local SAR have been developed by various standards authorities (e.g., Association of Radio Industries and Businesses (ARIB) in Japan [2]). These methods were developed mainly for application to localized exposure caused by using cellular telephones or similar wireless telecommunication devices. Hand-held amateur radio communication devices have received little attention.

The exposure conditions of the hand-held amateur radio communication devices and of the cellular telephones used in Japan are compared in Table 1. Hand-held amateur radio communication devices use lower frequencies (144 and 430 MHz) and higher antenna radiation power. Additionally, they are used differently. Hand-held amateur radio communication devices are mainly held in the front of the face while cellular telephones are held at the side of the head.

Table 1: Exposure conditions of hand-held amateur radio communication devices and cellular telephones used in Japan.

	Cellular Telephone	Amateur Radio Communication
Frequency	800 MHz	144 MHz
	1.5 GHz	430 MHz
		1.2 GHz
Radiation power	0.6 W	5 W (144 and 430 MHz)
		1 W (1.2 GHz)

Experimentally estimated SARs under similar exposure conditions have been reported for hand-held amateur radio communication devices [3–6] and cellular telephones [7, 8]. In those studies, various phantoms, from a solid type to a liquid type, were used. To estimate the local-peak SARs, a liquid phantom should be used because it is necessary to find the unknown position of the peak SAR by freely scanning the E-field probe in the liquid phantom. Although various liquid phantom materials have been developed [9,10], the frequencies designed for them are different from the frequencies used for hand-held amateur radio communication devices. Because of the frequency dependence of the electrical properties of those phantoms, they are not appropriate for experiments on hand-held amateur radio communication devices.

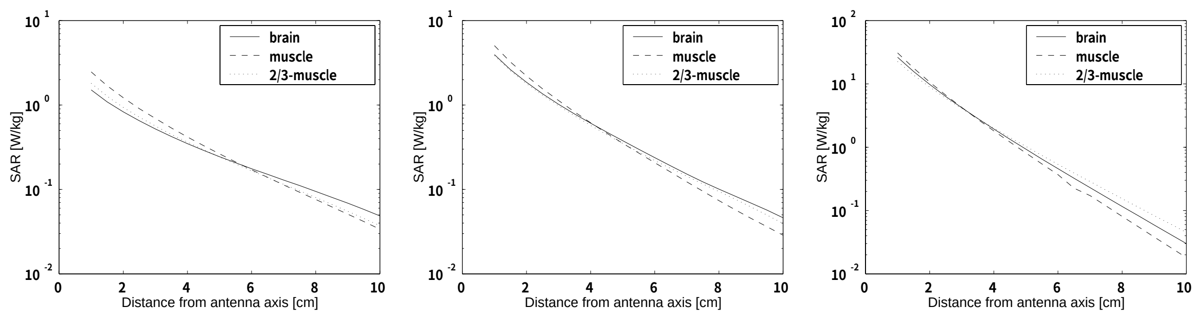
We have developed a tissue-equivalent liquid for experimentally evaluating the SAR distribution in a human body exposed to an electromagnetic field radiating from a hand-held amateur radio communication device.

2 Electrical Properties of Homogeneous Materials

Homogeneous phantoms are usually used for experimental SAR estimation because a heterogeneous phantom with liquid materials is difficult to manufacture. The homogeneous materials should be designed to simulate the worst-case condition, that is, the local-peak SAR value of the homogeneous phantom should be not less than the highest value of the actual local-peak SAR.

Two-thirds muscle tissue has been used as a homogeneous tissue for estimating the whole-body-averaged SAR [11], but not for estimating local-peak SARs. It is therefore necessary to identify an appropriate homogeneous tissue for local-peak SAR estimation.

We calculated the SAR distribution in a flat phantom exposed to the near-field of a 1/2-wavelength dipole antenna by using the finite-difference time-domain (FDTD) method. The electrical properties of muscle, brain, and 2/3 muscle were used for the electrical properties of the homogeneous tissue. The calculated SAR distributions are shown in Fig. 1. The highest peaks were obtained in the muscle-equivalent homogeneous material at 144 MHz, 430 MHz, and 1.2 GHz. The muscle phantom is thus appropriate for estimating the worst-case local-peak SAR value.



(a) 144 MHz (b) 430 MHz (c) 1.2 GHz

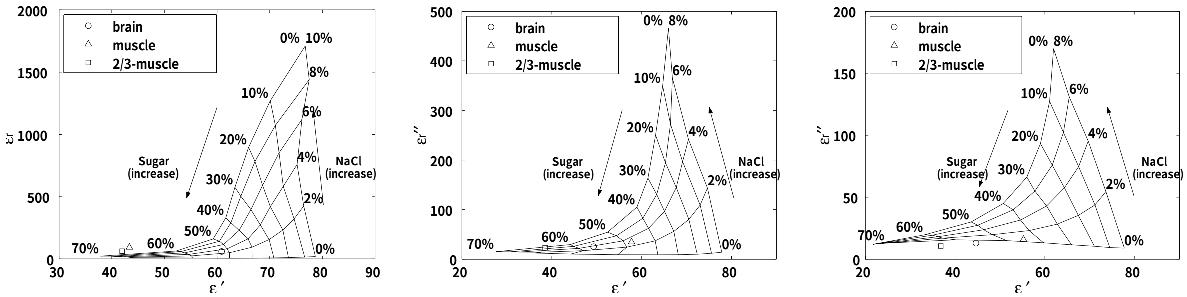
Figure 1: Calculated SAR distribution in flat homogeneous materials exposed to near-field of a 1/2-wavelength dipole antenna

3 Tissue-Equivalent Liquid

The tissue-equivalent liquid was made with water, NaCl, sugar (sucrose), hydroxyethylcellulose (HEC), and bacteriacide. The sugar decreases the dielectric constant of the water. The NaCl increases the $\tan\delta$ or conductivity. The HEC is used to prevent the deposition of the sugar in the water.

An open-ended coaxial probe (HP 85070B) was used to measure the electrical properties of the liquid materials. The accuracy of this measurement system was specified to be $\pm$ 5% for the dielectric constant and for the $\tan\delta$. The uncertainty of the conductivity was thus $\pm$ 10%.

The complex permittivity of the tissue-equivalent liquid for various ratios of the NaCl and the sugar are shown in Fig. 2. The complex permittivities of muscle, brain, and 2/3 muscle are also shown. The figure shows that the composition used in this study can be used to simulate the electrical properties of muscle tissue at 144 MHz, 430 MHz, and 1.2 GHz, but not of the brain and 2/3 muscle at 144 MHz and 1.2 GHz. To simulate the brain and 2/3 muscle, we might add several chemicals forming a microemulsion or hollow silica microspheres, which reduce the dielectric constant [9]. The recipes determined for the muscle-equivalent liquid are listed in Table 2.



(a) 144 MHz (b) 430 MHz (c) 1.2 GHz

Figure 2: Complex permittivity of tissue-equivalent liquid.

Table 2: Recipes for muscle-equivalent liquid.

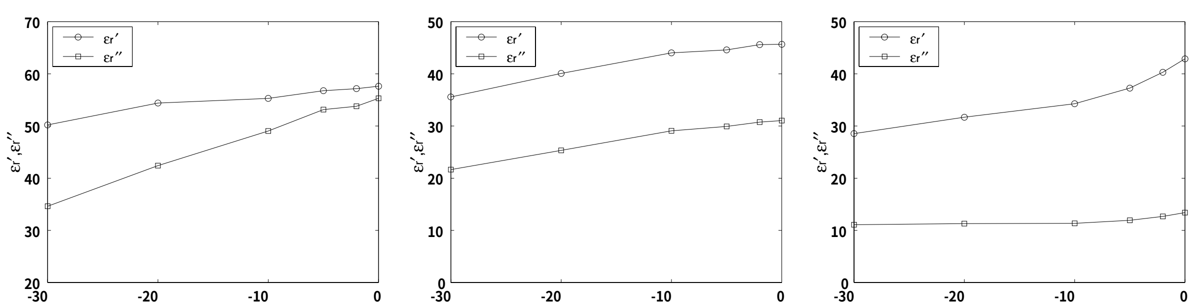
	144 MHz	430 MHz	1.2 GHz
Water	50.7%	50.8%	54.2%
NaCl	2.04%	1.59%	.160%
Sugar (sucrose)	49.0%	47.0%	45.0%
Hydroxyethylcellulose (HEC)	.199%	.583%	.550%
Bacteriacide	.0612%	.0583%	.0550%

4 Effects of Water Evaporation

The evaporation of water may also cause a large error in the measured electrical properties of the tissue-equivalent liquid. We therefore changed the ratio of water and measured the electrical properties. As shown in Fig. 3, the electrical properties depended greatly on the ratio of water. Additionally, the dependences of the phantoms at 144 and 430 MHz were different than at 1.2 GHz. To compensate for the evaporation, an appropriate volume of water to add can be determined from Fig. 3.

5 Conclusion

We have been developed a tissue-equivalent liquid for evaluating the specific absorption rate of RF fields generated by hand-held amateur radio communication devices. A homogeneous tissue appropriate for measuring the local-peak SARs was investigated by numerical simulation. We found that muscle tissue gives higher local-peak SARs value than brain and 2/3 muscle tissue. Recipes for muscle-tissue-equivalent liquid at 144 MHz, 430 MHz, and 1.2 GHz were determined. We also investigated the dependence of the electrical properties of the tissue-equivalent liquid on the ratio of water. They strongly



(a) 144 MHz (b) 430 MHz (c) 1.2 GHz

Figure 3: Effect of change in the ratio of water on electrical properties of muscle-tissue-equivalent liquid.

depended on the water ratio.

To establish an SAR measurement method for hand-held amateur radio communication devices, a method for calibrating the E-field probe in a liquid medium and the shape of the phantom should be developed.

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