A NEW METHOD FOR REALIZING LOCAL EXPOSURE TO YOUNG RAT HEADS USING ELECTRIC FLUX CONCENTRATION FOR BIO-EFFECT TEST OF MOBILE TELEPHONES

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Abstract: In this paper, we proposed a method to realize a highly localized exposure in young rat heads for bio-effect test of electromagnetic exposure from 1.5 GHz mobile telephones. Paying attention to the ability of electric flux concentration of ferroelectric material, we wound its flex sheet around the head part of a plastic rat holder, which is generally used to restrain the rat for obtaining a fixed exposure level, in order to induce a strong magnetic field inside the holder. Numerical simulations with an anatomically based young rat model showed that a ratio of 7 of the average specific absorption rate (SAR) in the brain to that in the whole body was realized. Exposure experiment with solid young rat phantoms also showed the validity of the method.
Key words: Bio-effect, mobile telephone, dosimetry, specific absorption rate, exposure setup.

1. Introduction

The recent rapid and ever more widespread use of mobile telephones has attracted public concerns regarding their possible biological effects for a long-term exposure during a period of growth for children. *In vivo* animal experiments are generally considered as a very useful means in the biological effect investigations. In testing the possible biological effects of electromagnetic exposure from mobile telephones in small animals such as young rats, it is essential to realize a highly localized head exposure as close as possible to the exposure actually occurring in a human head. To simulate such a situation in a young rat, the absorption power should be highly concentrated in the head, especially in the brain, while the whole-body averaged absorption power should be low enough not to cause any thermal stress. Since the safety guidelines applicable to mobile telephones in Japan prescribe a localized specific absorption rate (SAR) not exceeding 2 W/kg averaged over any ten grams of tissue [1], the design goal for an exposure system should be decided to realize both of (a) an average SAR above 2 W/kg in the animal brain and (b) an average SAR below 0.4 W/kg in the whole body. The latter goal (b) would be unlikely to cause any thermal stress in the animals. In other words, the ratio of the average SAR in the brain to the average SAR in the whole body should be larger than 5 at least. As a means to realize such a highly localized exposure in the small animal heads, a loop antenna is known to be a good choice compared to a linear dipole or monopole antenna [2].

In this paper, we proposed a method to obtain a high SAR in the brain region of young rats with a monopole antenna. This method is based on the consideration that a high electric flux should induce a strong magnetic field, and then result in a high SAR. Applying the method to a 1.5 GHz exposure setup for young rat, we demonstrated its validity via detailed numerical analyses and phantom experiments of dosimetry.

2. Method

Fig. 1 shows an *in vivo* exposure setup that was developed in Communications Research Laboratory for long-term bio-effect test of mobile telephones at 1.439 GHz [3]. The exposure box of the setup was made of metal, and its inside, except for the metal roof, were inlaid with pyramidal electromagnetic wave absorber. The metal roof acts as the ground of a 1/4-wavelength monopole antenna in the center of roof with a vertical orientation. The rats to be exposed are placed in a sector shape around the monopole antenna, with a distance of 30 mm from the antenna axis. To maintain a fixed exposure level in the rats, they are in general constrained with an acrylic holder to keep them in the vicinity of the antenna. If we cover each acrylic holder at the head part with a flex sheet having ferroelectric properties as shown in Fig. 2, the electric flux should be concentrated along the sheet in a circle, which results in a strong magnetic field inside the holder, i.e., the

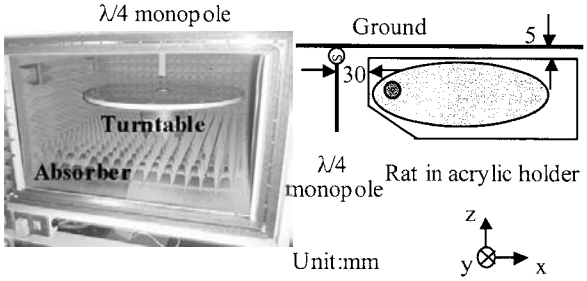


Fig. 1 Exposure setup and arrangement of a young rat in an acrylic holder.

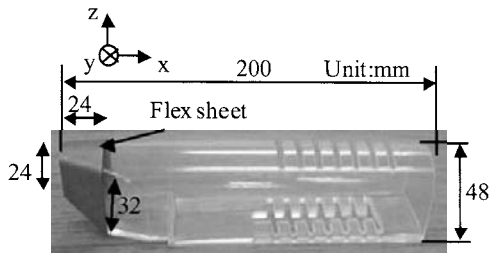


Fig. 2 Acrylic holder wound with flex sheet having ferroelectric properties.

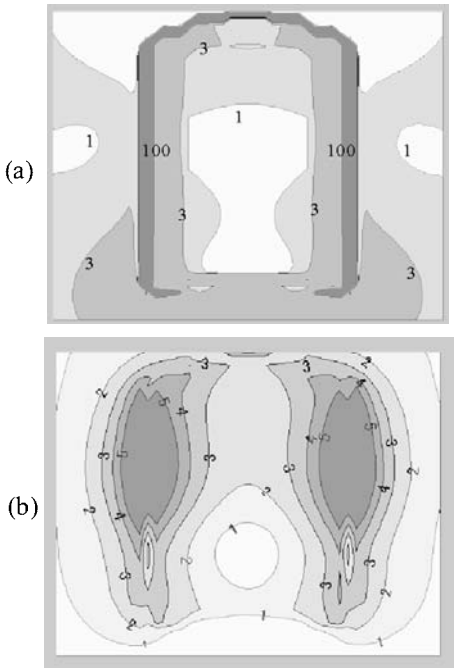


Fig. 3 (a) Electric flux density in the unit of nC/m^2; (b) magnetic field distributions in the unit of A/m in a yz plane inside the holder in the absence of rat.

region of rat head. According to the mechanism of electromagnetic absorption in tissue for mobile telephones, a strong magnetic field in the head region should induce a high SAR.

To demonstrate this phenomenon, we calculated the electric flux density and magnetic field distributions inside the acrylic holder in the absence of rat, using the finite-difference time-domain (FDTD) method. The whole computation domain enclosing the monopole antenna and the acrylic holder was constructed with 1-mm cubic cells, and the second Mur absorbing boundaries were employed to absorb outgoing scattered waves for simulating an electromagnetic absorber characteristic. The flex sheet was wound on the head part of the acrylic holder with a length of 24 mm and a thickness of 1 mm. Its complex relative permittivity was as high as 250-j10 and complex relative permeability was 5.6-j6.3 at 1.439 GHz. In the FDTD simulation, the metal roof and the monopole were simulated with perfect conductors. Others such as the acrylic holder and flex sheet were simulated with the cubic cells having their corresponding complex permittivity and permeability.

Fig. 3 shows the electric flux density and magnetic field distributions in a vertical cross-section (yz-plane) corresponding to the center of rat brain. Due to the ferroelectric properties of the flex sheet, we found a dramatic increase of the electric flux density along it, and also strong magnetic fields inside the holder in the head region. The strong magnetic fields should contribute to induce a high SAR in the head region when the rat exists.

3. Numerical Dosimetry

To quantify the SAR in the brain and whole body of young rats, we employed the FDTD method in conjunction with an anatomically based young rat model. The young rat model was derived by scaling down an anatomically based Sprague Dawley rat model [4]. The scaling-down yields a young-size model with a voxel size of 1 mm and 17 tissue types. Some modifications were made to realize a more realistic shape for simulating a young rat inside the acrylic holder. The dielectric properties of the rat model were cited from [5]. Fig. 4 shows the young rat model and the acrylic holder model with flex sheet wound on the head part. The young rat was placed just 5 mm beneath the metal roof and 30 mm far from monopole antenna as shown in Fig. 1.

Fig. 5 shows the SAR distributions in a sagittal cross-section of the young rat model. We found that with the flex sheet attachment the SARs in the rat head increased obviously, especially for the sheet with a width L = 24 mm. In addition, the results also suggest the existence of an optimum length of flex sheet, which depended upon the head size of rats to be exposed because the induced magnetic fields concentrated just around the sheet as shown in Fig. 3.

The numerical results for the average SAR in the brain and the average SAR in the whole body are tabulated in Table 1. All the results are normalized to a fixed average SAR of 2 W/kg in the brain. As can be seen in the table, compared to the case without the flex sheet attachment in which the ratio of the average SAR in the brain to that in the whole body

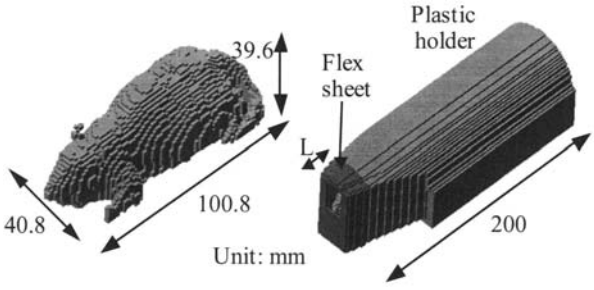


Fig. 4 Models of young rat and acrylic hold wound with flex sheet with high dielectric properties.

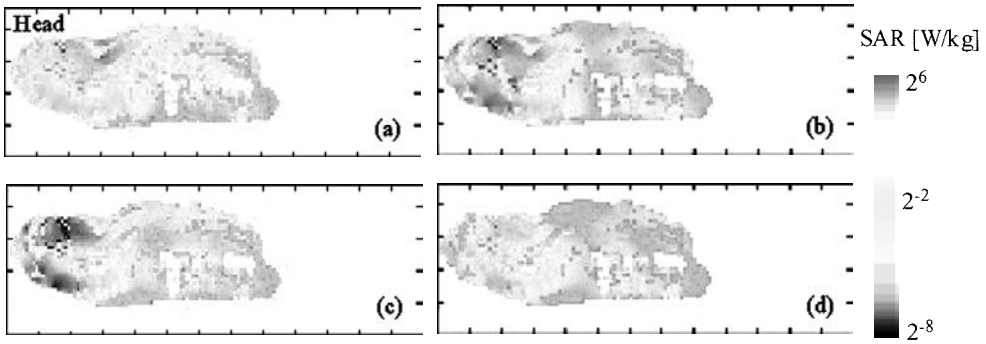


Fig. 5 SAR distributions in a sagittal plane of the young rat model. (a) Without flex sheet; (b) with flex sheet (L=12mm); (c) with flex sheet (L=24mm); (d) with flex sheet (L=36mm). The antenna input power is 1 W.

Table 1 Effect of flex sheet (L=24mm) on the SAR in young rat model

	Without flex sheet	With flex sheet		
Rat number	1	1	2	4
Ave. SAR in brain ①	2.0 W/kg	2.0 W/kg	2.0 W/kg	2.0 W/kg
Ave. SAR in whole body ②	0.639 W/kg	0.290 W/kg	0.286 W/kg	0.282 W/kg
Ratio of ①／②	3.1	6.9	7.0	7.1
Antenna input impedance	30.9-j21.8Ω	21.4-j25.2Ω	15.3-j26.9Ω	10.2-j27.9Ω
Required Power	269 mW	108 mW	123 mW	155 mW

was 3.1, the flex sheet attachment has resulted in a ratio of about 7 of the average SAR in the brain to that in the whole body. That is to say, for an average SAR of 2 W/kg in the brain, the average SAR in the whole body was only 0.29 W/kg. Even if we increase the number of exposed rats, the ratio of the average SAR in the brain to that in the whole body keeps almost constant, although more antenna power is required.

4. Experimental Dosimetry

The experimental dosimetry evaluation was conducted with homogeneous solid (gel with agar added) phantoms that had a similar but not completely identical shape to the numerical young rat model for ease of manufacture. Their conductivity and relative permittivity were found to be 1.1 S/m and 50.9, respectively, with a network analyzer and a dielectric probe kit (HP8753A + HP85046A). Fig. 6 shows the setup for experimental dosimetry evaluation. The antenna input power was 36 W, and the exposure time was 30 seconds. The SAR in the young rat phantom was measured with two methods, which are described below.

In the first method an infrared image camera (Nippon Avionics, TVS-8100MKII) was employed. The phantom before exposure was first set close to the ambient temperature, and the corresponding infrared image in a sagittal plane was recorded. After the 30-second exposure, the phantom was immediately removed from the exposure box and the infrared image was obtained again. Then from the difference of the above images, the temperature rise at the sagittal plane was obtained. Under the assumption of linear energy deposition within the 30-second period, the SAR was determined from $SAR = C_p dT / dt \approx C_p \Delta T / \Delta t$ where C_p is the specific heat (3770 J/kg°C), ΔT is the temperature rise due to the exposure, and Δt is the exposure time.

In the second method four flour-optic temperature probes (Luxtron, Model 790) were used in lieu of the infrared image camera. The temperature probes were inserted into the phantom and set at three locations along the mouse surface with 7-mm intervals and a 6-mm depth. The temperature reading at each location was recorded every 1/4 second over the 30-second period. Then the SAR at each location was determined in the same way as in the first method.

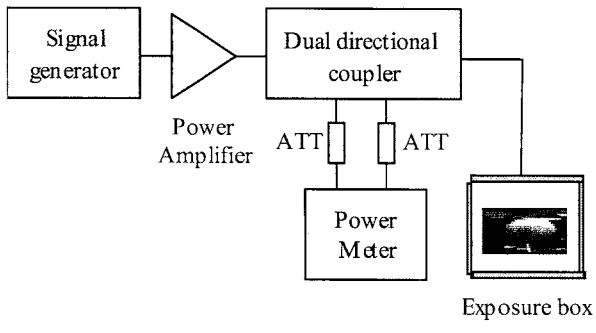
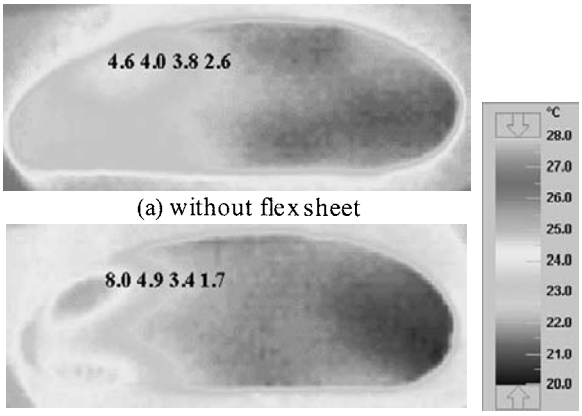


Fig. 6 Setup for experimental dosimetry evaluation.



(a) without flex sheet

(b) with flex sheet

Fig. 7 Infrared image in a sagittal plane of young rat phantom after an exposure of 30 s for an antenna input of 36 W. The values in the figure are the SARs in unit of W/kg measured with flour-optic temperature probes, normalized to an antenna input of 1 W.

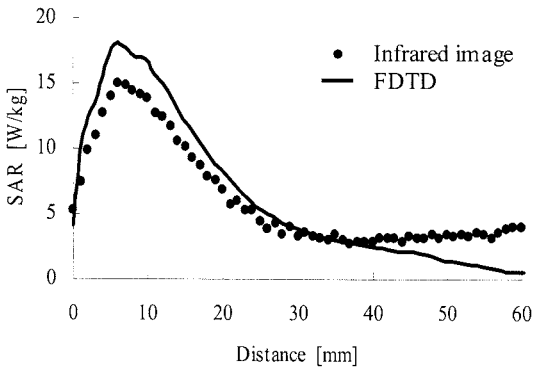


Fig. 8 SAR profile along a horizontal line inside the young rat phantom with a depth of 8 mm from the upper surface. The antenna input power was 1 W.

Fig. 7 shows the infrared image after 30-second exposure with an antenna input of 36 W at 1.439 GHz. The values in the figure are the SARs measured with the flour-optic temperature probes, which are normalized to an antenna input of 1 W. As expected, a localized exposure to the young rat brain was indeed realized.

Fig. 8 shows an SAR profile along a horizontal line inside the phantom with a depth of 8 mm from the upper surface. Also shown in the figure with a solid line is the SAR computed using the FDTD method in conjunction with the same homogeneous model. As can be seen, the experimental and numerical results had fair agreement. The total agreement among the measurement and FDTD computation assured the validity of the dosimetry analysis and the effectiveness of the proposed method. The somewhat lower SAR in the head region and higher SAR at the lower half of the rat phantom for the infrared image result were due to the diffusion of heat from high to low SAR areas during the period of time needed to remove the phantom to the outside of the exposure box in order to take the image.

5. Conclusion

We have developed a novel method that enables a local exposure in a young rat head while the average SAR in the whole body is low enough to cause no thermal stress. The local exposure in the head was realized by winding a flex sheet having ferroelectric properties on the head part of the acrylic holder. The electric flux concentration along the flex sheet then induced strong magnetic fields inside the holder, and consequently yielded a ratio of as high as 7 of the average SAR in the brain to that in the whole body. The validity of the method has been confirmed through both numerical simulations with an anatomical young rat model and experimental measurements with solid young rat phantoms.

Further issues are to optimize the exposure setup design including the material property optimization for electric flux concentration.

Acknowledgement

This study was performed with support from the Association of Radio Industries and Businesses (ARIB), Japan. The authors would like to thank Drs. S. Watanabe and K. Wake, Independent Administrative Institution, Communications Research Laboratory, Japan, for their help in the experimental dosimetry evaluation.

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