5-3 Development of Exposure Systems and Exposure Assessment for Studies on Biological Effect of Electromagnetic Fields

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There have been several biological studies to test possibilities of biological effects of electromagnetic fields. In this paper, development of exposure systems and exposure assessment for the studies on biological effects of electromagnetic field are introduced.

Keywords
Electromagnetic field, SAR, Exposure, Biological effect

1 Introduction

Recent years, there have seen growing concern over the possible biological effects of exposure to electromagnetic fields, and a variety of studies have been conducted on this subject. The World Health Organization (WHO) has established the International EMF (Electromagnetic Field) Project to investigate the biological effects of EMF exposure and has presented a number of necessary research themes for the assessment of potential hazards[1]. In Japan, the Ministry of Internal Affairs and Communications (MIC) has set up the Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields to facilitate various studies of this issue[2].

In order to conduct experiments on the biological effects of electromagnetic exposure, exposure assessments are required to allow precise quantification of actual exposure conditions. Systems are also required that will enable simulation of specific conditions of exposure. The Biomedical EMC Group within NICT is participating in the research activities of the MIC's Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields through an engineering-based approach, including development of exposure systems and exposure assessment. This report introduces some of the activities of the Biomedical EMC Group aimed at investigating the biological effects of electromagnetic exposure.

2 Head exposure experiments on rats

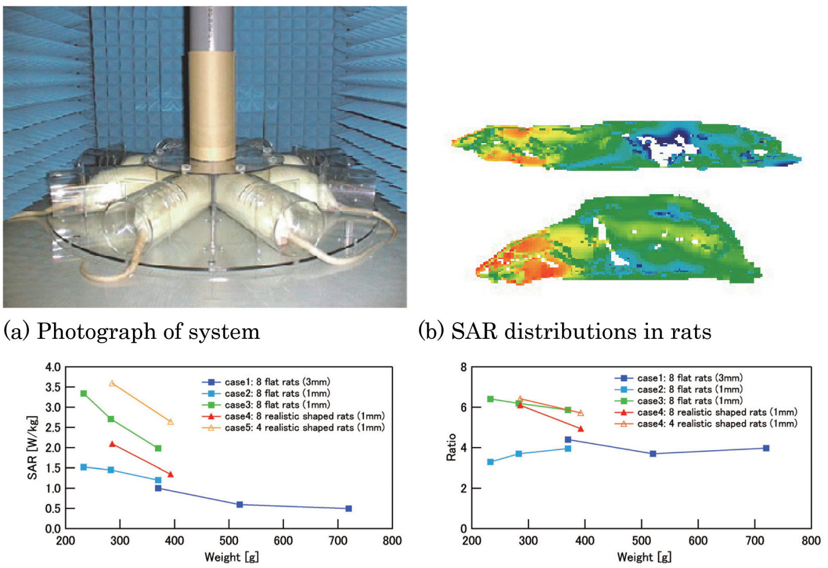
Rats are often used as the test animal for safety evaluation of chemical and other substances, and to date we have seen several experiments of localized exposure to EMF conducted on rat brains to simulate the conditions of cellular phone use by humans. However, it is known to be difficult to achieve localized exposure in rat brains, due to the relatively short body length of rats (approximately the same as the wavelength of the microwave-band radio signals employed by cellular phones). The degree of localization of exposure is often represented by the ratio of the average SAR (Specific Absorption Rate) value of the target tissue (such as the brain) to the average SAR of whole-body. Specifically, we can conclude that more localized exposure has been achieved when larger ratios are obtained.

2.1 Systems using a monopole antenna

The rat-head exposure system shown in Fig. 1(a) consists of a small radio-anechoic exposure box and a 1/4-wavelength monopole antenna[3]. The antenna is supplied with a 1.5 GHz Personal Digital Cellular (PDC) signal, part of a digital cellular system used in Japan. Several rats are fixed in plastic holders and placed in a radial manner around the antenna, facing the center, to enable localized exposure to the head. This exposure system has been used to investigate the effects of EMF exposure on blood-brain barrier (BBB) permeability[4], on learning[5], on the immune system and hormone secretion[6][7], on brain microcirculation[8][9], and more. The results reflected no apparent effects at exposure levels in compliance with the present Radiofrequency Radiation Protection Guidelines.

Initially, the SAR inside the rat body irradiated with this system was evaluated using a flat numerical rat model based on muscles relaxed rats under anesthesia. However, the actual animal experiments are performed without anesthesia, and the rats are therefore not flat. To allow for more accurate evaluation of SAR, rat models were developed based on X-ray CT images obtained for rats placed in the same posture as that in the exposure experiments. The number of animals placed around the antenna and their positions relative to the antenna vary among experiments. Figure 1(b) shows an example of the SAR distribution in rats, and Fig. 1(c) presents the brain averaged SAR for antenna input power of 1 W for various experimental conditions. The distance between the ground and the rat is 21 mm in most cases, except for Case 3, where the distance is 9 mm. Figure 1(d) shows the ratio of brain averaged SAR to whole body averaged SAR, which is an indicator of the degree of localized exposure in the brain. The ratios fall within a range from 3.5 to 6.5.

For the above exposure system, it was confirmed that relatively high SAR values are observed not only in the brain, which is the target tissue, but also in the jaw. Therefore, in order to improve the localization, the antenna feeder was moved closer to the target tissue by changing its position from the bottom surface to the lid of the enclosure and also by placing



(a) Photograph of system

(b) SAR distributions in rats

(c) Average SAR over brain

(d) SAR ratio of brain to whole body

Fig.1 *Exposure system using a 1/4-wavelength monopole antenna* the rat nearer to the lid[10]. Figure 2 (a) shows the modified exposure system. This system was used in a large-scale long-term exposure experiment to study the effects of two-year exposure to 1.5 GHz PDC signals on the generation of cerebral tumors using several hundred rats[11].

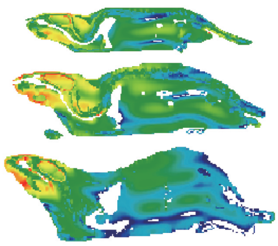
During the two-year period, the average body weight of the rats increased from less than 100 grams to over 400 grams, and their shapes also changed accordingly. Therefore, to secure stable localized exposure conditions for the specified brain averaged SAR, three different rat models (126 g, 263 g, and 359 g) were produced and used to perform SAR evaluations for rats of these various sizes. Figure 2 (b) shows the brain averaged SAR and whole-body averaged SAR at a fixed antenna input power of 1 W. The ratios of brain averaged to whole-body averaged SAR were calculated to fall between 2.7 and 7.0. In this animal bioassay on cerebral carcinogenesis, daily 90 minute exposure for a total of 300 rats was enabled by installing 10 units of the same exposure system, which allowed for simultaneous exposure in 100 rats. The input power of each antenna was controlled and recorded using a personal computer (PC). A similar exposure system has been developed for an animal bioassay for 2 GHz Wideband Code Division Multiple Access (W-CDMA) signal[12].

2.2 Systems with a loop antenna

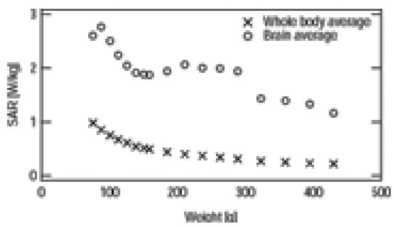
When simulating localized exposure conditions in humans during cellular phone use in an animal experiment, the localized exposure conditions for the head, as described in the exposure system discussed above, are not necessarily sufficient; a more highly localized exposure system is required. Accordingly, our group devised a corresponding exposure system using a loop antenna[13]-[15].

Figures 3(a) and (b) show an example of such a system. An exposure system incorporating a loop antenna requires a single antenna for each rat. This structure has the drawback of being unsuitable for large-scale experiments involving several hundred rats. However, this setup offers improved localization of SAR compared to previous systems. With the "8-shaped" loop antenna shown in Fig. 3(b), it is possible to observe biological effects at any time during the experiment through the space between the antenna and the cranial window formed on the head of the rat. This enables the observation of possible reversible biological

(a) Photograph of system

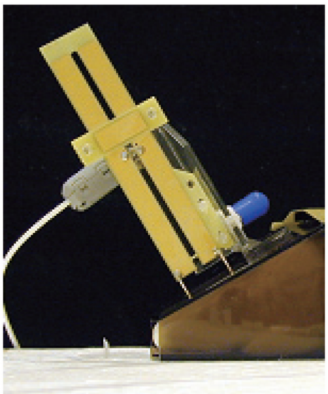


(b) SAR distributions in several sized rats

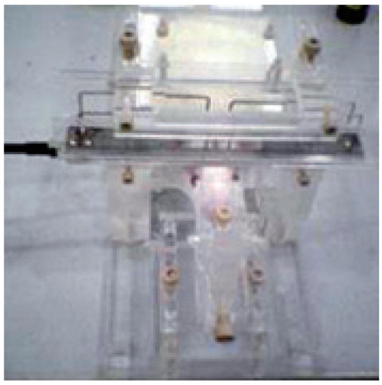


(c) Brain and whole body average SAR

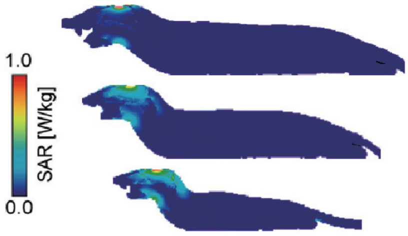
Fig.2 *Exposure system for a large-scale extended animal exposure experiment*



(a) Loop antenna with matching plate



(b) 8-shaped loop antenna



(c) SAR distributions in rats

Fig.3 *Exposure system with loop antenna*

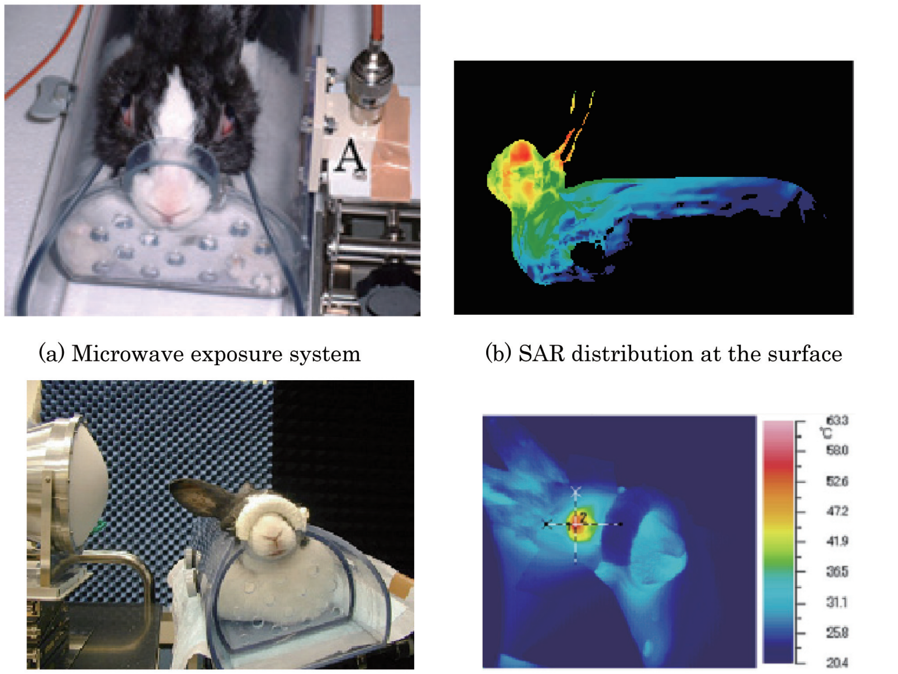
effects that may only occur during exposure[16]. Figure 3(c) presents examples of calculated SAR distribution in 4-, 8-, and 12-week-old rats irradiated by the present exposure system. When the brain in the observation field directly below the cranial window is set as the target area, the ratios of target-area to whole-body averaged SAR were calculated to be greater than 30. A similar exposure system is planned for use in an experiment to assess the biological effects of EMF on children using 1-, 2-, and 3-week-old rats.

3 Rabbit eye exposure experiments

The eye as an organ is thought to be sensitive to EMF exposure due to its relative lack of blood circulation and its location close to the body surface. Past studies have thus focused on investigating the effects of microwave and millimeter-wave exposure on rabbit eyes[17][18].

Figure 4(a) shows a system for subjecting rabbit eyes to exposure to 2.45 GHz microwaves[19]. A small coaxial-to-waveguide adapter filled with low-loss dielectric material is used as the antenna. This system allows for the generation of both continuous and pulsed waves by switching between the signal generators. Using a numerical rabbit model developed based on X-ray CT images, it was calculated that the exposed eye averaged SAR for exposure with an incident electric field intensity of 300 mW/cm^2 was about 100 W/kg. The ratio of exposed eye averaged to whole-body averaged SAR was 60.

Figure 4(b) shows a system for exposing rabbit eyes to 60-GHz millimeter-wave radiation. This system uses a lens antenna to confine the millimeter-wave irradiation to only the orb of the eye[20]. By switching between the two types of lens antennas, it is possible to experiment on two different exposure areas, with radii of 6 and 10 mm, respectively.



(a) Microwave exposure system

(b) SAR distribution at the surface

(c) Millimeter-wave exposure system

(d) Temperature distribution at the surface

Fig.4 *Rabbit eye exposure system*

4 Volunteer experiments

4.1 Exposure system for sensitivity experiment

The intensity of the electromagnetic field emitted from base stations and terminals of cellular phones cannot exceed the limits set by the Radiofrequency Radiation Protection Guidelines. However, in recent years, a number of studies have focused on Electromagnetic Hypersensitivity (EHS), in which the patient feels the effects of electromagnetic fields at intensities below the guideline values, suffering health problems as a result. The Netherlands Organization for Applied Scientific Research (known by its Dutch acronym, TNO) has reported that significant differences were observed in certain results for reaction time testing, recognition testing, and mental stability examined by psychological techniques between a group suffering from EHS and a group of normal, unaffected individuals when the groups were subjected to specific EMF exposure[21]. In response to such reports, an experiment on such sensitivity is underway in Japan to examine the possible psychological and physiological effects of W-CDMA EMF exposure and to collect objective evidence on whether humans can feel low-level EMF, even at intensities in compliance with the Radiofrequency Radiation Protection Guidelines[22]. The exposure system for this experiment was developed by our group[23]. Figure 5 shows the general scheme of the system. The present exposure system must be specialized to simulate EMF exposure from signals emitted from W-CDMA cellular base stations and must therefore incorporate safety designs to allow precise control of exposure level and to prevent excessive exposure. Subjects will be exposed to EMF in a special shielded room, and exposure will be controlled from a separate room. The subject will be exposed to EMF emitted from a double-ridged guide horn antenna placed 3 meters away. The antenna input power and the EMF intensity inside the shielded room will be monitored and fed back to the control room to achieve the desired conditions of exposure. To ensure the safe execution of the experiment,

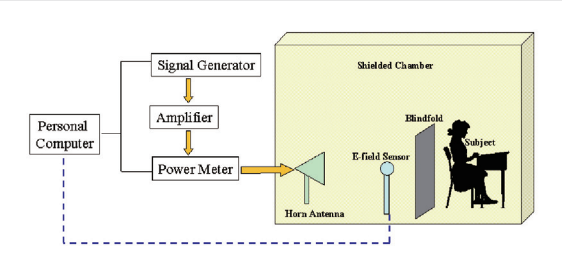


Fig.5 *Exposure system for the sensitivity experiment*

this system is equipped with a safety unit that either gives a warning or automatically terminates exposure in the event a value preset using specialized software is exceeded.

4.2 Warmth sensation experiment for millimeter waves

The use of the millimeter-wave band is expected to increase significantly with application of these waves to ITS and short-range large-volume data transmission, etc[24]. In the Radiofrequency Radiation Protection Guidelines, the warmth sensation is used as a basis for setting threshold values for the millimeter-wave band. However, existing experimental data on this sensation have mainly been collected in the far-infrared and microwave bands; as a result, data is lacking for the millimeter-wave band, in theory the main band of interest. Thus, experiments are underway to assess the threshold values for the warmth sensation in humans subjected to millimeter-wave band exposure[25]. Figure 6 shows an exposure system for a warmth sensation experiment. Subjects are exposed to millimeter-waves on the back, forearms, and upper arms using a 60 GHz millimeter-wave generator (3 W class) to investigate the relationship between the threshold of warmth sensation and the incidence power density, irradiation area, and irradiation time.

5 Epidemiological studies

The International Case Control Study of Tumors of the Brain and Salivary Glands (the ‘INTERPHONE Study’) is currently led and coordinated by the International Agency for Research on Cancer (IARC), a consultative organization of the WHO, and Japan is among the 13 countries participating in this collaborative study. In these epidemiological studies, indicators for exposure include not only the use (or non-use) of cellular phones and the duration of their use but SAR values as well. This is consistent with the frequent use of SAR in biological experiments to investigate the nonthermal effects of radiofrequency radiation, although there is presently no biological evidence associating cancer incidence with SAR generated in the head by radiofrequency

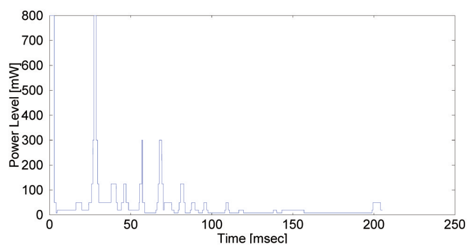
Fig.6 *Exposure system for experiment on warmth sensation*

radiation exposure due to the use of cellular phones. Furthermore, it should be noted that the SAR used in studies investigating the association of brain tumors and SAR must be measured in the same portion of the brain in which the tumor is found.

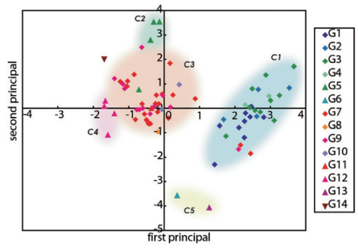
Various factors must be taken into consideration when investigating radiation exposure due to cellular phone usage for example, exposure time (duration of use), power, waveforms, system differences, spatial distribution of SAR inside the head, difference in SAR distribution between different terminals, etc. We have performed several researches on the exposure assessment for the epidemiological study, as follows: evaluations of power-level characteristics of cellular phone terminals under various conditions using a software-modified phone that records phone terminal output power level over time[26]; categorization of terminals into a small number of groups concerning SAR distribution in the head[27]; and investigation of a method to estimate 3-D SAR distributions in a realistic head model using the data obtained in accordance with the standard procedure for compliance testing[28]. Figure 7(a) presents an example of power-level measurement during a call using the specialized terminal, and Fig. 7(b) shows the distribution of scores obtained from a principal-component analysis using the SAR distribution characteristics of cellular phone terminals. Figure 7(c) is the estimated SAR distribution diagram in a human head model calculated from the SAR data for confined regions acquired in the course of compliance testing.

6 Concluding remarks

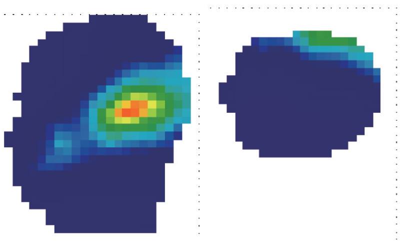
This paper has presented some examples of the development of exposure systems and exposure assessments conducted in studies promoted by the Committee to Promote Research on the Possible Biological Effects of Electromagnetic Fields[2] of the Ministry of Internal Affairs and Communications (MIC). The Biomedical EMC Group is currently conducting medical and biological studies on the physiological effects of such electromagnetic fields in order to confirm the validity of the Radiofrequency Radiation Protection Guidelines and to accumulate information that may form the basis of future guidelines.



(a) Power level variation of cellular phone



(b) Score of principal component analysis



(c) Estimated SAR distributions in a human head by cellular phones

Fig.7 *Exposure assessment for epidemiological studies*

References

1 http://spinspace.com/biophysics/wfoemf.htm.

2 http://www.tele.soumu.go.jp/j/ele/body/comm/index.htm

3 S. Watanabe et al., “A microwave exposure setup for the heads of Sprague-Dawley rats”, XXXVIth General Assembly of the International Union of Radio Science, p. 863, 1999.

4 G. Tsurita et al., “Biological and Morphological effects on the brain after exposure of rats to a 1439 MHz TDMA field”, Bioelectromagnetics, Vol. 21, pp. 364-371, 2000.

5 H. Yamaguchi et al., “1439 MHz pulsed TDMA fields affect performance of rats in a T-maze task only when body temperature is elevated”, Bioelectromagnetics, Vol. 24, pp. 223-230, 2003.

6 K. Hata et al., “Short term exposure to 1439 MHz pulsed TDMA fields dose not alter melatonin synthesis in Rats”, Bioelectromagnetics, Vol. 26, pp. 49-53, 2005.

7 H. Yamashita et al., “Short-term exposure to 1439-MHz TDMA signal dose not have the estrogen-like activity in rats”, 27th Annual Meeting of Bioelectromagnetics, pp. 178-179, 2005.

8 H. Masuda et al., “Acute effects of local exposure to radio-frequency electromagnetic fields on the cerebral microcirculation in rats”, 23rd Annual Meeting of Bioelectromagnetics, pp. 139-140, 2001.

9 H. Masuda et al., “Sub-chronic effects of local exposure to ragio-frequency electromagnetic fields on the cerebral microcirculation in rats”, 24th Annual Meeting of Bioelectromagnetics, pp. 30-31, 2002.

10 S. Watanabe et al., “Microwave exposure setup for a long-term in vivo study”, Proc. of 2000 International Symposium on Antennas and Propagation, Vol. 1, pp. 225-228, 2000.

11 T. Shirai et al., “Chronics exposure to a 1.439 GH electromagnetic field used for cellular phones dose not promote n-ethylnitrosourea induced central nervous system tumors in F344 rats”, Bioelectromagnetics, Vol. 26, pp. 59-68, 2005.

12 T. Shirai et al., “Review of Japanese in vivo studies on brain tumor carcinogenesis of cellular phones”, 27th Annual Meeting of Bioelectromagnetics, p. 507, 2005.

13 K. Wake et al., “Small loop antennas for localized head exposure setups of rats”, AP-RASC, p. 275, 2001.

14 H. Watanabe et al., “Dosimetry of rat-head SAR caused by a high-performance 8-shaped loop antenna”, 26th Annual Meeting of Bioelectromagnetics, pp. 52-53, 2004.

15 H. Watanabe et al., “Dosimetry of rat-head SAR caused by a high-performance 8-shaped applicator”, Proc. ISAP'04, pp. 801-804, 2004.

16 H. Masuda et al., “Real-time measurement of brain microcirculation during RF-EMF exposure using an 8-shaped loop antenna”, 27th Annual Meeting of Bioelectromagnetics, pp. 170-171, 2005.

17 M. Kojima et al., “Influence of anesthesia on ocular effects and temperature in rabbit eyes exposed to microwaves”, Bioelectromagnetics, Vol. 25, pp. 228-233, 2004.

18 M. Kojima et al., “Experimental setup to investigate ocular changes induced by millimeter-wave exposure”, 27th Annual Meeting of Bioelectromagnetics, pp. 433-434, 2005.

19 K. Wake et al., “Localized exposure system of 2.45 GHz microwave to the rabbit eye”, XXVIIth General Assembly of International Union of Radio Science, KA.P.6, 2002.

20 M. Hanazawa et al., “Antenna measurement for millimeter-wave exposure setup”, 27th Annual Meeting of Bioelectromagnetics, pp. 266-268, 2005.

21 A. P. M. Zwamborn et al., “Effects of grobal communication system radio-frequency fields on well being and cognitive functions of human subjects with and without subjective complaints”, FEL-03-C148, TNO Physics and Electronic Laboratory, 2003.

22 Y. Ugawa et al., "Studies on hypersensitivity to non-thermal radiofrequency electromagnetic field in Japan", 27th Annual Meeting of Bioelectromagnetics, pp. 24-25, 2005.

23 K. Wake et al., "System of Human Exposure to Radio-Frequency Fields of Cellular Base-Station for Studies on Electromagnetic Hypersensitivity in Japan", 27th Annual Meeting of Bioelectromagnetics, pp. 308-309, 2005.

24 http://www.soumu.go.jp/joho_tsusin/pressrelease/japanese/housou/000421j703.html

25 T. Konno et al., "A study of warmth sensation produced by millimeter wave expsure", XXVIIIth General Assembly of International Union of Radio Science, K01.3, 2005.

26 K. Wake et al., "Variation of power level of cellular phone", General Conference of Institute of Electronics, Information and Communication Engineering, p. 363, 2005. (in Japanese)

27 K. Wake et al., "Statistical analysis of SAR distributions in human head nearby cellular phone devices", 27th Annual Meeting of the Biolectromagnetics Society, p. 227, 2003.

28 K. Wake et al., "Estimation of 3D SAR distributions from mobile phone compliance testing data for the local exposure assessment in epidemiological study", XXVIIIth General Assembly of International Union of Radio Science, KAE.5, 2005.

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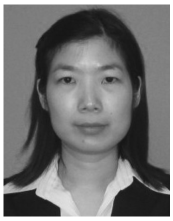

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Dosimetry of Human Exposure to Radiofrequency Radiation