Statistical Dosimetry Analysis in Whole-Body Exposure Setup Based on Rat's Activity Behavior

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Abstract

For a whole-body exposure setup of rats, the rats can freely move in the cage in most cases. In order to determine the specific absorption rate (SAR) variation during the entire exposure period, a statistical analysis for the rat activity behavior in the exposure period is necessary. In this study, we divide the rat cage in the exposure box into nine small areas, and derive the stay frequency of rat in each area based on the classification of the documentary photos of rat activity. Using the stay frequency as a weighting factor, we calculate the statistical characteristics of the whole-body average SAR for the rats during the entire exposure period. Such an approach gives a high quality determination of the exposure level.

1. Introduction

Radio frequency (RF) base stations are raising a public concern about their possible biological effects especially for children. This has triggered many animal experiment of whole-body exposure to rats over a multi generation [1]. The design of the exposure system is based on the consideration that the exposure to human from a base station includes various couplings, and the exposed rats can move freely in the exposure box. The finite difference time domain (FDTD) method is generally used to evaluate the whole-body specific absorption rate (SAR) in conjunction with anatomical rat models. In this case one has to simulate various rat positions in the cage when they are exposed. Then an average SAR is used to determine the exposure level. For example, in our developed circularly polarized exposure setup [2], we derived the exposure level by assuming a uniform probability for the rat positions in the cage.

However, from the observation of the activity of rats in the cage, we found that the rats do not stay in each area in a uniform possibility if we divide the cage into several small areas. This means that a simple average of the SARs in various positions does not give an accurate estimation on the actual SAR during the entire exposure period. In this paper, therefore, we take a number of photos to record the activity pattern of the exposed rats in the cage. Based on the classification of the documentary photos of rat activity, we derive the stay frequency of the rats in each area. Using the stay frequency as a weighting factor, we estimate the average SAR for the pregnant rats and the new-born rats during the entire exposure period.

2. Exposure Setup

The investigated exposure setup was designed at 2 GHz band to have two features: (1) a circularly polarized antenna which makes the field polarization change in an equal probability from E-polarization to H-polarization and then to K-polarization with time; and (2) a relatively uniform electric field distribution which makes the variation of the whole-body SAR of the unrestrained rats be within ±60% with respect to the designed average SAR level. Fig. 1 shows the structure of the exposure box. The exposure box is made of metal with a dimension of 90 cm x 90 cm x 40 cm. Its inside, except for the roof, is paved with 6-cm-thick planar RF absorber. The circular polarization is realized approximately by using two 3/2-wavelength dipole antennas under the roof that intersect at right angles and have a phase difference of 90^o. The exposed rats are kept in four plastic cages at the bottom of the box with a distance of 20 - 26 cm (1.4 - 1.8 wavelengths) under the antenna. Each cage has a translucent acryl removal cover, and inside the rats can move freely.

3. Activity Pattern

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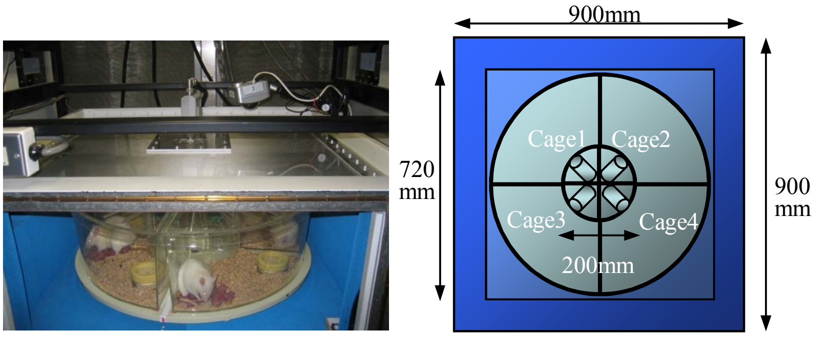
The long-term exposure experiment was designed to have three stages. The first stage was the one under pregnancy. In this stage there was one pregnant rat in each cage. The second stage was the one after birth. In this stage there were one mother rat and eight new-born rats. This stage continued until three weeks after birth. From the fourth week after birth, i.e., the third stage, there were only four young rats in each cage. It is indispensable to grasp the activity pattern of rats in the exposure box for simulating a real exposure situation. We therefore recorded the action of the mother rats and the new-born rats using a web camera in the day time and an infrared camera in the night time, respectively. The rat positions were recorded every ten minutes every day. We divided each cage into nine small areas, and then identified the rat position to a single small area in each photo. From these position data, the stay frequency of the rats in each small area was extracted in each exposure stage.



(b) Actual side view (b) Top view

Fig. 1 Whole-body exposure setup

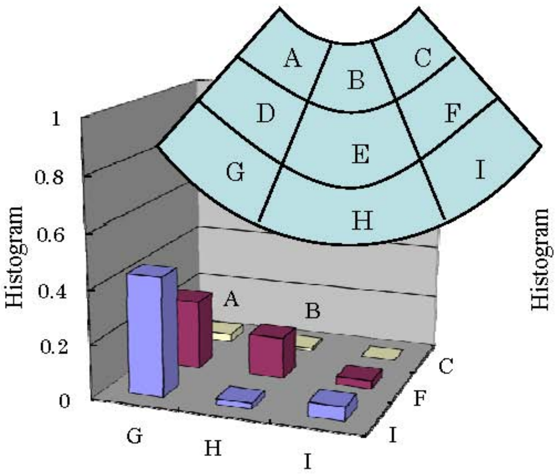


Fig. 2 Histogram of rat positions in the 2nd week after pregnancy

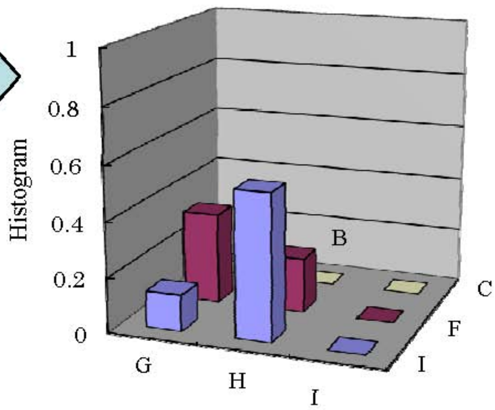


Fig. 3 Histogram of new-born rat positions in the 3rd week after birth when the mother rat is in area G

Fig. 2 shows the histogram of stay frequency in each area in the second week after pregnancy, which was obtained from more than 300 photos. It can be seen that the rats stay more frequently in the small areas G and D. This characteristic keeps almost the same for the rats of the first week and the third week after pregnancy, i.e., in the entire period of the first stage.

In the second stage, i.e., after birth, there were one mother rat and eight new-born rats in each cage. Based on an analysis for more than 300 photos, we found that the new-born rats are always together in the first and second weeks after birth. That is to say, the new-born rats always locate in the areas G and D, while the mother rat is in the areas G, D or C, near the new-born rats in most cases. However, with the growing up, the new-born rats start to move around the cage. In the third week after birth, they are not always near the mother rat. Fig. 3 shows the histogram in which the activity area of the new-born rats expands to the small areas D, E, G and H.

After the new-born rats were weaned (we call them young rats from the fourth week after birth), we had four young rats in each exposed cage. In this exposure stage, also based on more than 300 photos, we divided the young rat activity patterns into three situation: (1) the four young rats were in the same area; (2) three young rat were in one area and another one rat was in another area; and (3) two young rats were in one area and another two young rats were in another area. The probability whether there are four young rats together is about 30%. In addition, the young rats are found in the small areas D, E and G in most cases.

4. SAR Analysis

Since the histogram data of the stay frequency reflect the activity pattern of rats in the exposed cage, we used them to scale the whole-body SAR in order to get a statistical average for quantifying the actual exposure level. At first, we calculated the whole-body SAR when the rats were in each small area using the FDTD method. After obtaining the SAR values for the rats in each small area, we used the histogram data as weighting factors to include the stay frequency effect of rats in each area. For example, in this stage, the weighted average SAR was obtained as follows:

$$SAR = \sum_{n=A}^{I} w_n SAR_n$$

where w_n is the weighting factor of the pregnant rat in the small area n ($n = A, B, \ldots, I$), and SAR_n is the average SAR when the pregnant rat is in the small area n. We used the stay frequency of the pregnant rat in each small area as the weighting factor w_n, and the sum of all the weighting factors is one.

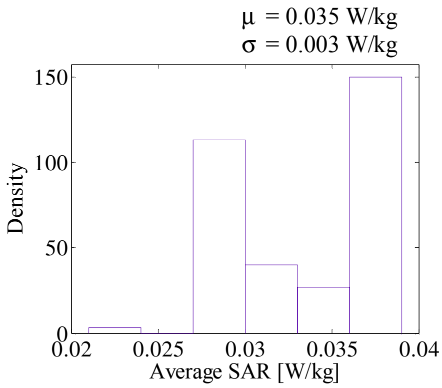


Fig. 4 PDF of the whole-body SAR for the pregnant rats of the 2nd week

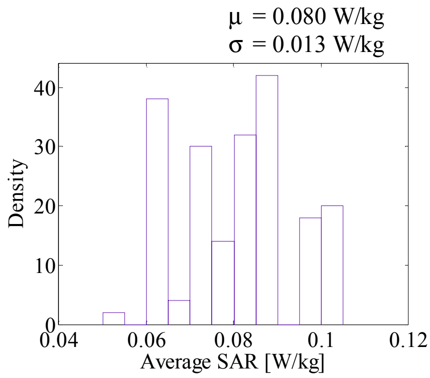


Fig. 5 PDF of the whole-body SAR for the new-born rats in the 2nd week after birth

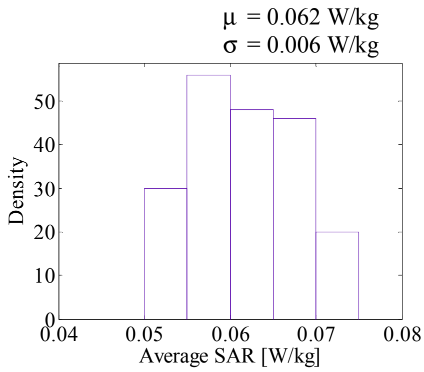


Fig. 6 PDF of the whole-body SAR for the young rats in the 5th week after birth

As a result, for the pregnant rat of one week and two weeks, a difference up to 6.6% was found between the weighted average SAR and the uniform average SAR. Fig. 4 shows the probability density function (PDF) of the whole-body SAR in each small area in the second week after pregnancy. It was found that the PDF exhibits an irregular shape.

The average SAR with the maximum frequency is 0.037 W/kg. This value is not identical to but is larger than the statistical mean μ = 0.035 W/kg, i.e., the weighted average SAR. The standard deviation σ is about 10%.

After birth, the mother rat was in the area G or D or C in the first two-weeks. In the third week, the mother rat was more frequently in the area G, D, I and A. Based on the analysis result of photos, we used the following equation to calculate the weighted average SAR for the new-born rats, i.e.,

$$SAR = \sum_{m=C,D,G} \sum_{n=A}^{I} w_{mn} SAR_{mn}$$

in the first and second week, and

$$SAR = \sum_{m=A,D,G} \sum_{n=A}^{I} w_{mn} SAR_{mn}$$

in the third week after birth, where m indicates the stay area of mother rat, and n indicates the stay area of new-born rats. Fig. 5 shows the PDF of the average SAR for the new-born rats in each small area in the second week after birth. It was found that the PDF also exhibits an irregular shape. The average SAR with the maximum frequency is also somewhat larger than the statistical mean μ, i.e., the weighted average SAR. The standard deviation σ reaches 16% at maximum. The differences are also around 6% between the weighted average SAR and the uniform average SAR for the new-born rats.

After the new-born rats were weaned (we call them young rats), they grew up rapidly. Their activity pattern in this stage was similar. The weighted average SAR can be obtained from the following equation:

$$SAR = w_1 \sum_{n=A}^{I} w_{1n} SAR_{1n} + w_2 \sum_{n=A}^{I} w_{2n} SAR_{2n} + w_3 \sum_{n=A}^{I} w_{3n} SAR_{3n}$$

where w_m (m=1, 2, 3) is the frequency corresponding to the above-mentioned three situations, and $w_1+w_2+w_3=1$. Fig. 6 shows the PDF of the average SAR for the young rats in each small area in the fifth week after birth. In this stage, the PDF is a little near the normal distribution. However, the average SAR with the maximum frequency is smaller than the weighted average SAR. This trend is different from the pregnant rats and new-born rats.

5. Conclusion

Since the exposed rats can move freely in whole-body exposure setups, it is necessary to clear the uncertainty due to the rat movement on the whole-body SAR. In this study, we have divided the rat cage in the exposure box into nine small areas, and derived the stay frequency of rats in each area based on the classification of the documentary photos of rat activity. Using the stay frequency as a weighting factor, we have calculated the whole-body SAR for the pregnant rats and young rats during the entire exposure period. As a result, we have found that the PDF of the average SAR in each small area have an irregular shape which looks different from the Normal distribution. As a result, the average SAR with the maximum frequency is not identical to the weighted SAR or the statistical mean SAR. This finding has emphasized the importance to design a uniform field distribution in the exposed cage. It also raises a question in determining the exposure level in actual animal experiments, i.e. which SAR value, the weighted SAR or the maximum-frequency-SAR should be used?

6. Acknowledgments

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7. References

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