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Correlation of SAR and Temperature Increase Induced in the Human Body Due to Body-Mounted Antennas at 400 MHz and 900 MHz Bands

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1. Introduction

In recent years, there has been an increasing concern about adverse effects of electromagnetic (EM) wave on humans. Mobile telephones are often singled out since they are used in close proximity to the user's head. According to safety standards regulated by public organizations, peak spatial-average SAR is used as a measure for RF near field exposures. However, possible physiological effects or damage in humans for EM wave exposures could be caused by the temperature increase. Therefore, the temperature increase in the anatomically based human head model for exposure to EM waves from handset antennas has been calculated in several works (e.g., [1,2,3,4]). In particular, we have revealed that the maximum temperature increases in the head and brain are approximately proportional to peak SARs in the corresponding regions [4].

Little attention has been paid to body-mounted antennas, which are commonly used in occupational environment. The main frequency bands are 80, 150, 400, 900 MHz, and so forth, which are dependent on each country. The output power of these antennas is up to 5.0 W and much larger than those of commercial mobile phones. In this paper, first, we investigate the SAR and temperature increase in the human body due to a dipole antenna, which is attached to the neck, waist, and abdomen. Then, the correlation between the peak SAR and the maximum temperature increase is discussed, as is the case with the head.

2. Methods and Model

The human body model used in this paper is obtained from the Internet Site of Brooks Air Force Base [5]. It consists of 196 X 114 X 626 cubic cells, whose side cell length is 3.0 mm. This model is comprised of 38 tissues, that is, skin, bone, muscle, fat, nerve, blood, white matter, gray matter, cerebellum, and so forth.

The FDTD method is used for investigating the interaction between the human body model and EM waves. In order to incorporate the inhomogeneous head model into the FDTD scheme, the dielectric properties of the tissues are required. They are determined with the aid of the 4-Cole-Cole extrapolation. It should be noted that 2/3 muscle is considered as a homogeneous medium. As a wave source, a dipole antenna at 400 MHz and 900 MHz is considered. The diameter and length of the dipole antenna are fixed to 1.0 mm and 360mm for 400MHz and 150mm for 900MHz, respectively. The output power is 1.0 W. Three positions of the antenna are considered, that is, behind the back, waist, and neck of the human body. The temperature increase in the body is calculated by solving the bioheat equation. The SAR calculated by the FDTD method is used as a heat source. For calculating

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the peak 10-g SAR, the scheme proposed by IEEE [6] is used.

3. Numerical Results

Figure 1 illustrates the SAR and temperature increase distributions in the body model at the antenna-body distance of 54mm. Note that the antenna is located behind the neck. Comparing these distributions, the temperature-rise distributions are largely affected by the SAR distributions, and the former are not linearly proportional to the latter. In particular, the temperature-rise distributions are much smoother than the SAR distributions. This is because of heat diffusion, which is governed by the bioheat equation. These results are consistent with the results in previous articles [1,2,3].

The correlation between peak 10-g SAR and maximum temperature increase is discussed, as is the case with the head [4]. As is mentioned above, three body parts are considered. For each body part, twenty-seven feeding points are considered (See Fig.2). Figure 3 shows the correlation between the peak 10-g SAR and maximum temperature increase. From Fig.3, the maximum temperature increase is reasonably proportional to the peak 10-g SAR. The slope of the regression lines is different with the parts of the body. The values of the slope are 0.24 for the neck, 0.24 for the waist, and 0.18 ^{o}C Kg/W for the back. They are comparable to that due to handset antenna at 900 MHz- 2.45 GHz (021-0.24 ^{o}C Kg/W) [4].

In order to investigate this correlation thoroughly, the effect of a local blood blow on the correlation is discussed. Note that the correlation is little affected by the heat conductivity, heat capacity, relative permittivity, and conductivity of tissues [7, 8], although they are not shown here because of the lack of space. The realistic human body model is homogenized as the 2/3 muscle. Then, the blood flow of the tissue is considered as variable. Figure 4 shows the dependency of the slope correlating between the maximum temperature increase and peak 10-g SAR on the local blood flow. For comparison, the results using the rectangular parallel-piped model with the dimension of 513 X 333 X 633 are also shown. Added to this, the results using the inhomogeneous model are also plotted. Note that the local blood flow is defined as the average value of blood flow in the volume chosen for the calculation of peak 10-g SAR. From this figure, the slopes are slightly affected by the position of the antenna (up to a few tens percents). This is caused by the curvature of the model. The plots using the inhomogeneous model are well on the slopes obtained by the homogeneous model. Thus, it is found that the slopes are mainly determined by the local blood flow and the curvature of the model around the position where the peak 10-g SAR appears.

The effect of the frequency and different antennas on this correlation is discussed. The frequency bands considered are 400 MHz and 900 MHz. As antennas, a monopole antenna on a metallic box is applied in addition to the dipole antenna. Figure 5 shows the dependency of the correlation between peak SAR and maximum temperature increase on the above-mentioned factors. From this figures, the effect of the frequency on this correlation is not large for the dipole antenna. On the other hand, this is not true for the monopole antenna. The reason for this is that the SAR distribution is concentrated around the back for the monopole antenna at 900 MHz, while around the neck for the other cases. This is caused by the effect of the metallic box, which affects the current distribution.

4. Summary

This paper investigates the SAR and temperature increase due to body-mounted antenna at 400 MHz and 900 MHz bands. As a main result, a strong correlation was observed between peak SAR and maximum temperature increase in the body, as is the case with EM wave exposures from handset antennas.

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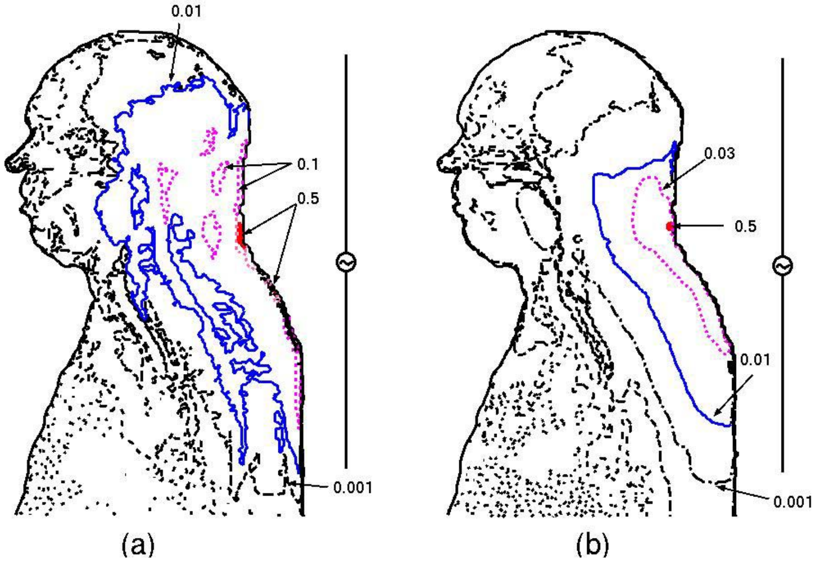

Fig.1 (a) SAR and (b) temperature increase distributions in the human body.
The antenna is located behind the neck.

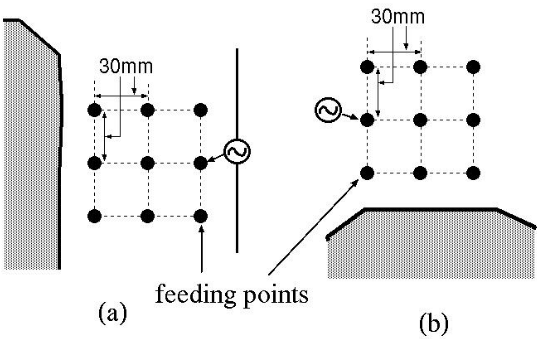

Fig.2 Feeding points of the antenna: (a) side view and (b) top view.

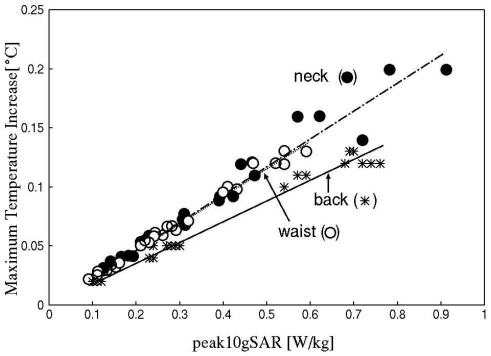

Fig.3 The peak 10-g SAR versus the maximum temperature rise in the body.

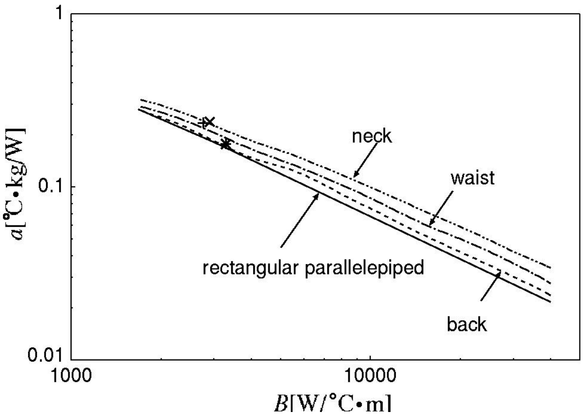

Fig.4 The effect of the body on the correlation between peak 10-g SAR and the maximum temperature rise in the body.

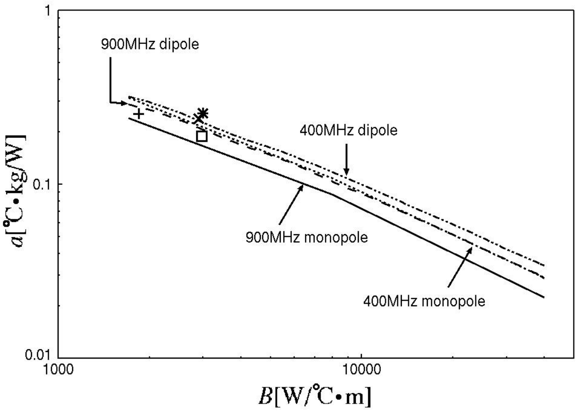

Fig.5 The effect of different antennas and the frequency of the antenna on the correlation between peak 10-g SAR and the maximum temperature rise in the body.