SAR analysis in the eye of human whole-body model for plane-microwave exposure

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Abstract: We numerically analyze the specific absorption rate (SAR) in the eye of anatomically based human whole-body model exposed to E-polarized plane wave in the frequency range from 0.6 to 4 GHz. As a result, we find a clear resonance that the average SAR is about 57% larger at the maximum than that of the isolated head.

Keywords: biological effects, SAR, eye, body effect, microwave

Classification: Electromagnetic Compatibility (EMC)

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1 Introduction

The human eye comprises some of the most sensitive body tissues as far as electromagnetic (EM) wave exposure is concerned. At the same time, wireless personal communication is a rapidly expanding sector, particularly in the field of portable telephones used near the eyes. Thus, it is important to have a fast and reliable means of evaluating the specific absorption rate (SAR) in the eyes. The SAR in the human eye for microwave and millimeter-wave exposures has been analyzed by various head models [1, 2]. The use of the head model is based on the size of the eye being sufficiently small relative to that of the human body at higher frequencies. In near-field exposure for portable telephones, the EM wave concentrates near the head so that the head model is sufficient for the SAR analysis of the eye [3]. However, since the EM plane wave is uniformly exposed to the whole body, further discussions are necessary, especially for E-polarized plane wave exposure. It is namely important to estimate how the head approximates the whole body, although modeling roughness are relatively allowed for electromagnetic dosimetry. We previously evaluated it with the human simple model [4].

In this letter, we analyze the body effect on the SAR in the eye of the human anatomical head model exposed to E-polarized plane wave in the frequency range from 0.6 to 4 GHz.

2 Model analysis and discussion

Fig. 1 illustrates the Brooks anatomically realistic human model [5] exposed to E-polarized plane wave, and the cross section of the eye. The frequency and power of the plane wave are represented $f$ and $P_i$, and the eye consists of 4 tissues and is about 7.3 g of mass. It is a printing limit that the sclera appears to be torn in the cross section of the eye as indicated in Fig. 1. Since the eye of the original model is closed, the eyelid was cut into nearly ellipse which is about 23 mm in a major axis and 9 mm in a minor axis, in order to make open eye [6]. The isolated head is set as $h = 25$ cm from the top containing a part of the shoulder. We use a self-written finite-difference time-domain (FDTD) program of a resolution of 1 mm implementing the 8 layers uniaxial PML as the absorbing boundary. The SAR of the left and right eyes is not the same in a human being. We treat only the right eye because the difference between them is small.

To calculate the SAR of the eye, it is considered that the whole body is not required. In order to estimate it, the average SAR when $h$ is changed is shown in Fig. 2(a) where the closed and open circles represent the cases at $f = 0.6$ GHz and...
2.8 GHz, and $P_i = 5 \text{ mW/cm}^2$ which is the maximum permissible exposure limit in the guideline of controlled environments over $f = 1.5 \text{ GHz}$ [7]. The average SAR cannot be obtained accurately in the isolated head. The shortest size that can be approximated to the whole body is required to be about $h = 70 \text{ cm}$ at $f = 0.6 \text{ GHz}$ and $h = 60 \text{ cm}$ at $f = 2.8 \text{ GHz}$. In the following, we call the model of $h = 80 \text{ cm}$ as a whole body. Fig. 2(b) shows the frequency characteristic of the average SAR in the eye, where the solid and the dotted lines represent the whole body and isolated head, and $P_i = 5 \text{ mW/cm}^2$. The resonance occurs clearly at $f = 1 \text{ GHz}$, 2.2 GHz, and 3.4 GHz in the whole body while slightly in the isolated head. The reason is that a large hot spot [1] is formed in the eye as noted later. The both difference at these frequencies is about 57%, 30%, and 21%. Also, it is about −34% at 0.6 GHz.

The SAR distributions in the central $yz$ plane of the eye at $f = 1.0 \text{ GHz}$, 2.2 GHz, and 3.4 GHz in Fig. 2(b) are shown in Figs. 3(a), (b), and (c) where the left and right represent the whole body and isolated head. Reflecting the characteristics of Fig. 2(b), the peak SARs of the whole body are almost unchanged in position and large as compared to those of the isolated head. Furthermore, the largest hot spot is formed at 2.2 GHz in which the wavelength in the tissues is substantially the same as the size of the eye. There is roughly the peak SAR on the upper inside the eye. This is because the incident wave is scattered by the nose and

![Figure 2](image_url)

**Fig. 2.** (a) Average SAR in the eye when $h$ is changed, and (b) frequency characteristics of average SAR in the eye; $P_i = 5 \text{ mW/cm}^2$. 

hence the incident energy to the upper part is strengthened. In Fig. 3(c) where the plane wave is less likely to penetrate, small hot spot occurs on the inside, although the SAR is large on the surface. At some frequencies, we estimate why the SAR of the whole body is larger than that of the isolated head as can be seen from Figs. 2(b) and 3. Since the consideration is difficult to only the SAR inside the eye, the internal and external electromagnetic fields of both models were calculated. In the whole body model, the electromagnetic field at the front of the head is enhanced by phase matching between the scattered waves from the chest and abdomen with the incident wave, and hence the SAR inside the eye increase. In the head model, this phenomenon does not occur. Finally, we confirm the reliability of the result in the head model compared with another. At $f = 1.5$ GHz, the average SAR is 0.858 W/kg in the model of Fig. 1, while it is 1.25 W/kg in the model of Ref. [1]. The difference is caused by the height and the shape of model and the mass in the eye. In addition, the eye in Fig. 1 is dented, while that in Ref. [1] is not. Consequently, the frequency of the maximum average SAR is different in each model.

3 Conclusion

We analyzed the SAR in the human eye exposed to E-polarized plane wave in the frequency range 0.6 to 4 GHz using a whole-body model. The main findings are as follows. The whole body can be approximated by about 80 cm from the top of the head in the SAR analysis. The resonances in the eye are clearer than those of the isolated head. At 2.2 GHz of the resonant frequencies, the maximum average SAR is about 30% larger than that of the isolated head.

Fig. 3. SAR distributions in the central yz plane of the eye at (a) $f = 1.0$ GHz, (b) $f = 2.2$ GHz, (c) $f = 3.4$ GHz; Left- whole body, Right- isolated head, $P_i = 5$ mW/cm$^2$. 

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It is still estimated that the maximum average SAR is sufficiently smaller than the threshold of 10 W/kg averaged over 10 g of tissues in the guideline of controlled environments [7].