Specific absorption rates of pregnant females and their fetuses from simple and realistic electromagnetic sources

Akihiro Tateno\textsuperscript{1a)}, Kensuke Tanaka\textsuperscript{1}, Tomoaki Nagaoka\textsuperscript{2}, Kazuyuki Saito\textsuperscript{1}, Soichi Watanabe\textsuperscript{2}, Masaharu Takahashi\textsuperscript{1}, and Koichi Ito\textsuperscript{1}

\textsuperscript{1} Chiba University, 1–33, Yayoi-cho, Inage-ku, Chiba-shi, Chiba, 268–8562, Japan
\textsuperscript{2} National Institute of Information and Communications Technology, 4–2–1, Nukui kita-machi, Koganei-shi, Tokyo, 184–8795, Japan
\textsuperscript{a)} a.tateno@chiba-u.jp

Abstract: As the electromagnetic (EM) environment becomes increasingly diverse, it is essential to evaluate exposures to EM waves for pregnant females and their fetuses. Therefore, we have determined the maternal and fetal specific absorption rates (SARs) of pregnant females at the 13th, 18th, and 26th gestational weeks using a high-definition numerical model of a flip phone in close proximity to the pregnant female’s abdomen. The results indicate that the difference between the simple EM source and the realistic one in the maternal and fetal SARs is within 30% in this case. Moreover, all calculated SARs were below the international safety guidelines.

Keywords: fetus, wireless radio terminal, specific absorption rate, finite-difference time-domain method

Classification: Electromagnetic Compatibility (EMC)

References


1 Introduction

As portable telecommunications technology based on electromagnetic (EM) waves has been developing and its use has been rapidly expanding, an increasing number of people, including pregnant females, are being exposed to EM waves from EM devices such as mobile phones. Absorbed EM energy in the human body mainly imparts a thermal effect to tissues. The specific absorption rate (SAR: [W/kg]) is used as the standard dosimetric parameter for international safety guidelines [1] for radio frequency exposures.

The effects of EM waves radiating from antennas held by pregnant females have become one of the major concerns for EM safety in recent years [2]. Fortunately, we can numerically estimate the SAR in a pregnant female and her fetus with high accuracy using anatomically accurate computational pregnant female models [3, 4]. Togashi et al. [4] estimated SARs for a fetus radiated from the planar inverted-F antennas (PIFAs) within a metallic case as an EM source using the 26th gestational week pregnant female model. However, it was simple to simulate actual mobile radio terminals.

In this study, we compared SARs for a pregnant female and fetus from a simple EM source model, i.e., PIFAs, to those from a high-definition EM source model of a mobile communication terminal [5]. Moreover, we evaluated the relation between the maternal and fetal SAR and the gestational age.

2 Materials and methods

Fig. 1 (a) illustrates the PIFA models within a metallic case having a $2 \times 2 \times 2$ mm$^3$ voxel grid as simple EM sources, and the reflection coefficient in free space calculated by commercially available finite-difference time-domain (FDTD) software, XFDTD ver.7.2.2.2 [6]. Fig. 1 (b) illustrates the high-definition source model of a closed flip phone model. For the model, $0.1 \times 0.1 \times 0.1$ mm$^3$ voxel grid was generated from the computer aided design (CAD) model. The reflection coefficients in free space are also shown in Fig. 1 (b).

A transmitting antenna in the flip phone model was connected to the printed circuit board by a feeding and shorting, as shown in Fig. 1 (b). The PIFAs and transmitting antenna in the flip phone model resonated at the 900 MHz and 2 GHz frequencies. Endo et al. [7] confirmed the agreement between
SAR calculation results and measurement ones when these PIFA models were placed in the vicinity of the tissue-equivalent phantom. Our SAR calculations correspond to the results of [7] under the same conditions. Moreover, we confirmed the SAR calculations from the flip phone model close to the tissue-equivalent phantom were also in good agreement with the SAR measurements using a dosimetric assessment system (DASY). In order to consider for the worst case evaluation, the input powers of both EM source models were 0.25 W at both frequencies under consideration representing the maximum power of the 3rd generation (3G) mobile communication system. In addition, we did not consider the mismatch loss when the EM sources were placed in the vicinity of the human body. Therefore, the calculated SARs are higher than that under actual conditions.

Fig. 1. Structures of simple and realistic EM source models

In this study, we used numerical models of pregnant females with a fetus at the 13th, 18th, and 26th gestational weeks [3]. Tables I (a) and I (b) list the electrical properties of the fetal and gestational tissues [4] and the densities of fetal tissues [3], respectively.

Fig. 2 (a) illustrates the sagittal planes including the feeding point in the case of the flip phone model. Each placenta of the 13th, 18th, and 26th gestational week pregnant female models is placed in the –y-direction from the fetus. The distance between the surface of the flip phone model and surface of the pregnant female model is 10 mm, and the height of the feeding gap is set at the center of the fetal head to simulate the worst case scenario
of EM absorption at the fetal head. The calculation conditions in the case of the PIFA models, such as the distance between PIFAs and maternal surface and height of the feeding gap, were same for those in the case of the flip phone. The calculations were performed by XFDTD ver.7.2.2.2 [6].

Table I. Physical properties of fetal and gestational tissues

<table>
<thead>
<tr>
<th>Tissues and organs</th>
<th>900 MHz</th>
<th>2 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative permittivity</td>
<td>Electric conductivity [S/m]</td>
</tr>
<tr>
<td>Fetal body</td>
<td>62.9</td>
<td>1.17</td>
</tr>
<tr>
<td>Fetal brain</td>
<td>60.9</td>
<td>1.16</td>
</tr>
<tr>
<td>Fetal eyes</td>
<td>68.9</td>
<td>1.64</td>
</tr>
<tr>
<td>Amniotic fluid</td>
<td>71.6</td>
<td>1.60</td>
</tr>
<tr>
<td>Placenta</td>
<td>59.6</td>
<td>1.26</td>
</tr>
</tbody>
</table>

(b) Densities of fetal tissues [kg/m³]

<table>
<thead>
<tr>
<th>Tissues and organs</th>
<th>13 gestational week model</th>
<th>18 gestational week model</th>
<th>26 gestational week model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetal body</td>
<td>970</td>
<td>970</td>
<td>980</td>
</tr>
<tr>
<td>Fetal brain</td>
<td>970</td>
<td>970</td>
<td>980</td>
</tr>
<tr>
<td>Fetal eyes</td>
<td>1,018</td>
<td>1,024</td>
<td>1,028</td>
</tr>
</tbody>
</table>

3 Results

Fig. 2 (b) shows the peak maternal 10-g-averaged SARs from the PIFA (simple) models and the flip phone (realistic) model. At 900 MHz, the largest difference between the maternal SARs from the simple and realistic model is 25% for the 13th gestational week model. At 2 GHz, the largest difference is 20% for the 13th gestational week model. The maternal 10-g-averaged SARs vary with gestational week because of the difference in the shape of the maternal abdomen due to development of the fetus.

Fig. 2 (c) shows the peak fetal 10-g-averaged SARs from the PIFA models and the flip phone model. At 900 MHz, the largest difference between fetal SARs from the simple and realistic model is 9% for the 18th gestational week model. At 2 GHz, the largest difference is 27% for the 13th gestational week model. The fetal 10-g-averaged SAR from the flip phone model at 900 MHz is the highest for the 26th gestational week model (approximately 0.12 W/kg); however, the highest fetal SAR is approximately one fifth that of the maternal SAR from the flip phone model at 900 MHz for the 26th gestational week model. Comparing the frequencies, fetal SARs at 900 MHz are higher than those at 2 GHz, in contrast to that of the maternal SARs. This is because the wavelength at 900 MHz is longer than that at 2 GHz, and therefore the EM wave at 900 MHz penetrates the maternal body more
In the case of the flip phone model, the peak fetal 10-g-averaged SAR is higher as the gestational age progresses at both frequencies. This is because the fetal 10-g-averaged SARs in these three pregnant female models depend on the distance between the fetus and EM source. As the gestation age progresses, the distance becomes shorter because of the growth of the fetus and dilation of the maternal abdomen (Fig. 2(a)). Moreover, the SAR values at 900 MHz are 1.5–4.6 times higher than those at 2 GHz in all gestational weeks. Again, the wavelength at 900 MHz is longer than that at 2 GHz; therefore, the EM waves at 900 MHz penetrate the maternal body more deeply. For the same reason, the SARs from the PIFA model have the same tendency as that of the flip phone model. The highest fetal and maternal SARs out of the mismatch loss were approximately 0.12 W/kg and 1.36 W/kg, respectively. In addition, these values were below the safety guidelines sufficiently (2 W/kg) [1].

Fig. 2. Positions of source models and results of 10-g-averaged SARs.

4 Conclusion

In this study, we estimated the maternal and fetal SARs in pregnant females exposed to EM waves radiated from simple EM sources (PIFA models) and a realistic EM source model (flip phone model) using 13th, 18th, and 26th gestational week pregnant female models. Operating frequencies at the antenna of both EM sources were 900 MHz and 2 GHz. We found that the difference between the simple EM source and the realistic one in the maternal and fetal...
SARs is within 30% in this case, and also the fetal SARs are substantially lower than the maternal SARs for each gestational model. We also confirmed that maternal SARs at 2 GHz are higher than those at 900 MHz; on the other hand, fetal SARs at 2 GHz are lower than those at 900 MHz because of the radiation penetration depth, and the fetal SARs become higher with increasing gestational age for both simple and realistic EM sources.

Acknowledgments

Part of this work was supported by the Strategic International Cooperative Program (Joint Research Type) of the Japan Science and Technology Agency. Especially, Dr. Joe Wiart, France Telecom Orange Labs, and Prof. Christian Person, Telecom Bretagne, contributed to this program.