Metal-Framed Spectacles and Implants and Specific Absorption Rate Among Adults and Children Using Mobile Phones at 900/1800/2100 MHz

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Metal-Framed Spectacles and Implants and Specific Absorption Rate Among Adults and Children Using Mobile Phones at 900/1800/2100 MHz

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The specific absorption rate (SAR) from mobile telephones at horizontal and vertical positions is investigated in human adult and child heads wearing metal-rim spectacles and having metallic implants. The SAR values calculated by Finite Difference Time Domain (FTDT) method are compared to the actual ANSI/IEEE standards and to the 900/1800/2100 MHz electromagnetic radiation limits according to EU standards. Our calculation shows a maximum of the cellular SAR in the child head, which in the case of metallic implant could be as much as 100% higher than in the adult head. The averaging on 1 and 10 g tissue-masses shows SAR generally under the limit of 519/1999/EC standards. However, in the case of 2100 MHz with vertical position of the phone for adults and of the 900 MHz for children with metallic implants the ANSI/IEEE limits are exceeded.

Keywords Metal implant; Metal-rim spectacles; Mobile-phone; SAR.

Introduction

The rapid development of electromagnetic (EM) environment, the occurrence of related health problems, and the scientific research continuously compete with each other. It is ascertainable that the intensive technical development precedes the others.

In an average household, one of the most intensive EM sources is the mobile phone. The number of users has been growing from 1990, and in Hungary reached 8,000,000 subscribers in 2004 (the number of inhabitants is 10,000,000) (Figyelő, 2004).

The degree of local exposure can be much higher than that issued from the other household appliances and may reach the value of 1000–1500 µW/cm² (Thuróczy and Bakos, 2002). This is a near field radiation type and its absorption efficiency in the human head is rather high (40–70%). The most significant parameter characterizing
the health risks at 900/1800/2100 MHz frequencies is the specific absorption rate (SAR), defined as

\[
\text{SAR} = \frac{\sigma |E|^2}{2\rho},
\]

where \(E\) [V/m] is the maximum value of the internal electric field, \(\sigma\) [S/m] is the tissue conductivity, and \(\rho\) [kg/m\(^3\)] is the mass density.

The interaction between the EM fields and biological matter is rather complex because the EM waves and the living tissues modify the properties of each other. This process is also influenced by the regulation mechanism of the human tissues (circulation, perspiration, respiration, etc.). The absorbed energy depends not only on the parameters of EM fields (frequency, power density, polarization, near/far field, etc.) but also on the characteristics of the exposed body (dimensions, inner/outer geometry, electric properties of tissues, clothing, etc.) and the reflection coefficient of the adjacent objects.

The maximum allowable values of SAR are specified in radiation protection standards (1999/519 EC in the EU, ANSI/IEEE C95.1-1992, Table 1 in the USA). These standards specify the basic restrictions obtained from health effects by using safety factors. Regarding the limitations we make a distinction between the general public and occupational exposure. The measured or calculated SAR values are averaged over a specific time period (usually 6 or 30 min) and mass of tissues (1 or 10 g).

At the study of interaction between the humans and mobile phones, most of the studies concentrate on the absorbed energy in an adult head using standard models. Almost all the experimental and theoretical models applied for the description of absorbed energy use full scale models based on adult body measurements.

Recently, however, the increasing use of mobile phones by children has brought up public debate on the possible harmful effects of the phones to young people and the necessity of creating a child model. Based on the so-called Stewart report (IEGMP, 2004) there might be differences on the effects of radiofrequency (RF) fields for adults and children. This idea is supported by Gandhi et al. (1996) and Gandhi and Kang (2001) particularly at 835 MHz. They calculated larger penetration and higher local SAR (averaged to 1 g) in the child head model. Conversely, Hombach et al. (1996) or Schönborn et al. (1998) concluded that the

<table>
<thead>
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<th>Table 1</th>
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<tr>
<th>Guideline</th>
<th>Frequency range</th>
<th>Localized SAR (head and trunk)</th>
<th>Localized SAR for occupational exposure (head and trunk)</th>
<th>Averaging mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999/519/EC</td>
<td>100 kHz–10 GHz</td>
<td>2</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>ANSI/IEEE C95.1-1992</td>
<td>30 kHz–300 GHz</td>
<td>1.6</td>
<td>8</td>
<td>1</td>
</tr>
</tbody>
</table>
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spatial peak SAR is hardly affected by the size and shape of human model at 900 and 1800 MHz. The results of Martínez-Búrdalo et al. (2004) at 900/1800 MHz show that the maximum 1 g (SAR\(_{1g}\)) and 10 g averaged SAR (SAR\(_{10g}\)) trends downwards with decreasing head size, but as the head size decreases, the percentage of energy absorbed in the brain decreases. Setting the radiated power to the values used currently (0.25 W for 900 MHz and 0.125 W for 1800 MHz) we get similar values for the peak SAR\(_{1g}\) and SAR\(_{10g}\) for models of different sizes. Their findings agree completely with the results of Lee et al. (2002).

Wang et al. (1998) analyzed the increase of SAR caused by metal-framed spectacles for 1.5 GHz mobile phones, and found an increase of maximum 1.2 times for the 10 g averaged SAR in the head and maximum 2.75 times for the 1 g averaged SAR in the eye. The higher SAR distribution is assigned to the current induced on the metal frame.

According to Wang and Fujiwara (2003) the contradictory results of other groups may be due to the different boundary conditions applied in their numerical SAR calculations. Available comparisons of SAR values in various head sizes are contradictory in the relevant literature, (e.g., Gandhi et al., 1996; Gandhi and Kang, 2001; Hombach et al., 1996; Schönborn et al., 1998; Martínez-Búrdalo et al., 2004; Lee et al., 2002). Effect of metal-rim and the metal implants were not widely studied. The metal-rim effects were investigated at 450 MHz (Wang et al., 1998) and 1500 MHz (Troulis et al., 2003) showing increased SAR in the head. They explained the effect by the induced current in the rim.

In accordance with our observations the modeling methods used earlier to characterize mobile phone exposures often have faults:

- the usually applied radiated power at the examined frequencies and the metal objects (metal-rim spectacles, metal implants) are not considered;
- the head-mobile phone distance is not taken as zero; however, the phone is regularly used very close to the ear;
- radiated dipole is used, only a rough model of the mobile phone;
- one head-mobile position is examined only without changing the geometry of the head (during the matrix transformation the head was slightly changed).

In this study these problems are eliminated, and the local SAR in scaled human head models is analyzed in order to specify differences between the SAR in the heads of adults and children in terms of energy absorption while using mobile phone at 900, 1800, and 2100 MHz. The applied model is in compliance with international guidelines. The examinations are widened to the exposure modification effects of metal implants and glasses as well.

Material and Methods

During mobile phone and base station communication one part of the RF energy is absorbed in the human body and the other part is radiated into free space. We have to solve Maxwell’s equations to specify the electric (E) field and hence the SAR. Analytical solution exists only for simple geometries such as sphere, cylinder, or ellipsoid. The Finite Difference Time Domain (FDTD) method might be an alternative way, which gives a discrete approximate solution of the Maxwell equations in space and time (Iványi, 2003; Kunz and Lübbers, 1992; Sullivan, 2000; Taflove and Hagness, 2000). The basis of the method is the so-called Yee cell by
the help of which any complex geometries could be approximated. In general, an FDTD solution yields acceptably accurate results for numerical dosimetry if the Courant stability condition is fulfilled, and grid cell sizes of less than 1/10 of the shortest wavelength in any material in the FDTD mesh at the highest frequency of interest are used (Taflove and Hagness, 2000). During the simulations, the SAR was calculated in every 50th time step, and when the difference between the successive results was smaller than 1% the program run was stopped.

The program was validated by canonical numerical simulations and experimental studies (Joó and Szász, 2004). The radiated power was set to the value generally used at mobile phones (900 MHz–0.25 W; 1800 MHz–0.125 W; 2100 MHz–0.125 W). The body of mobile phone just came into contact with the external surface of the ear (the distance between the phone and head is 0).

From the point of view of electrical properties the human tissues are rather complex but magnetically similar to the free space ($\mu_r \sim 1$).

The reconstruction of head geometry and the identification of tissues at certain points were carried out by the help of MRI sections. The data were obtained from the image set of Radio Frequency Radiation Branch (Mason et al., 2000). It is a 2 mm resolution model distinguishing 25 different tissues ($293 \times 170 \times 939$ cells). The model was detruncated at the shoulders and neck (Figure 1) giving the resolution of $140 \times 145 \times 140$. The electric parameters of human tissues were determined by a program based on Gabriel 4 Cole–Cole parameters to be accessed at http://niremf.iroe.fi.cnr.it/tissprop (Table 2).

![Figure 1. Human model geometry from MRI image set (a) full body model, (b) detruncated model, (c) sagittal section of head model.](image-url)
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Table 2
Density and electric properties of human tissues

<table>
<thead>
<tr>
<th>Tissue</th>
<th>900 MHz</th>
<th>1800 MHz</th>
<th>2100 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\rho$ [kg/m$^3$]</td>
<td>$\varepsilon_r$</td>
<td>$\sigma$ [S/m]</td>
</tr>
<tr>
<td>skin</td>
<td>1125</td>
<td>41,4052</td>
<td>0.866751</td>
</tr>
<tr>
<td>cerebrospinal liquid</td>
<td>1007.2</td>
<td>68,6386</td>
<td>1.53791</td>
</tr>
<tr>
<td>bone (cortical)</td>
<td>1990</td>
<td>12,4636</td>
<td>0.143312</td>
</tr>
<tr>
<td>bone (cancellous)</td>
<td>1920</td>
<td>20,7877</td>
<td>0.339994</td>
</tr>
<tr>
<td>white matter</td>
<td>1038</td>
<td>38,8863</td>
<td>0.590799</td>
</tr>
<tr>
<td>tooth</td>
<td>2160</td>
<td>12,4536</td>
<td>1.08</td>
</tr>
<tr>
<td>nerve (spin)</td>
<td>1038</td>
<td>32,5306</td>
<td>0.73681</td>
</tr>
<tr>
<td>ligaments</td>
<td>1220</td>
<td>45,8254</td>
<td>0.718356</td>
</tr>
<tr>
<td>muscle</td>
<td>1046.85</td>
<td>55,0319</td>
<td>0.942965</td>
</tr>
<tr>
<td>cerebellum</td>
<td>1038</td>
<td>49,4441</td>
<td>1.26278</td>
</tr>
<tr>
<td>air</td>
<td>1.3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>glands</td>
<td>1050</td>
<td>59,6837</td>
<td>1.03852</td>
</tr>
<tr>
<td>muscosus membran</td>
<td>1040</td>
<td>46,0813</td>
<td>0.844813</td>
</tr>
<tr>
<td>lymph</td>
<td>1040</td>
<td>59,6837</td>
<td>1.03852</td>
</tr>
<tr>
<td>cartilage</td>
<td>1097</td>
<td>42,653</td>
<td>0.782389</td>
</tr>
<tr>
<td>eye</td>
<td>1008.9</td>
<td>68,9018</td>
<td>2.41262</td>
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<tr>
<td>(aqueous humor)</td>
<td>1070</td>
<td>55,2354</td>
<td>1.39429</td>
</tr>
<tr>
<td>eye (cornea)</td>
<td>1026</td>
<td>55,2706</td>
<td>0.79339</td>
</tr>
<tr>
<td>lens</td>
<td>1053</td>
<td>46,5727</td>
<td>0.942257</td>
</tr>
<tr>
<td>gray matter</td>
<td>1038</td>
<td>52,7522</td>
<td>0.143312</td>
</tr>
<tr>
<td>body fluid</td>
<td>1010</td>
<td>68,9018</td>
<td>1.63617</td>
</tr>
<tr>
<td>blood</td>
<td>1058</td>
<td>61,3603</td>
<td>1.16684</td>
</tr>
<tr>
<td>blood vessels</td>
<td>1040</td>
<td>44,7752</td>
<td>0.696131</td>
</tr>
<tr>
<td>fat</td>
<td>916</td>
<td>5,46195</td>
<td>0.051043</td>
</tr>
</tbody>
</table>

The child models were created from adult models by rescaling the cell dimensions (adults = 2 mm; children of 9–10 = 2 × 0.88 = 1.76 mm; and children of 2–3 = 2 × 0.78 = 1.56 mm) (NIST, 2004).

During the simulation the same tissue parameters were used for adults and children and the dispersive feature of the tissues was neglected. The frame of the glasses was modeled as a perfect electric conductor (PEC) and the lens as a PVC ($\varepsilon_r = 2.46$, $\sigma = 4.46 \times 10^{-4}$ S/m).

The metal implant was placed behind the ear in order to replace the bone under the skin by using PEC in the diameter of 10 cm. The mobile phone was positioned in the horizontal and vertical positions and brushed the outer lap of the ear. The center of rotary notion was the ear piece. As a result, there are 72 simulation setups in all (3 frequencies, 3 head models, and 2 mobile phone positions with and without implant and glasses). The typical simulation setups are demonstrated in Figure 2 and the mobile phone in Figure 3.
Figure 2. Typical simulation setups.

Results

We have made the SAR calculations at the frequencies of 900/1800/2100 MHz, and obtained similar results as shown in Figure 4. The sections have been taken at maximal values of the local SAR parallel with the x-y plane. The SAR_{1g} and SAR_{10g} can be seen in the table.

Conclusions

The most important conclusions from our simulations are as follows.

When using 900 MHz mobile phone the absorbed RF power is higher in the case of children of 9–10 than for adults. At further scaling of the head, the values
of $\text{SAR}_{1\text{cellmax}}$, $\text{SAR}_{1\text{gmax}}$, $\text{SAR}_{10\text{gmax}}$ decreased, and in the plane of $\text{SAR}_{1\text{cellmax}}$. The penetration of EM fields for adults was more significant than in the case of children. In the head of children of 9–10 and adults wearing glasses the SAR decreased (41%) because of the spreading effect of metal frame. On the effect of implanted metal the obtained $\text{SAR}_{1\text{cellmax}}$ value significantly increased, and its position moved inside the head both for adults and children of 9–10.

Our observation is that at vertically positioned 900 MHz mobile phone and models without implant and glasses the $\text{SAR}_{1\text{cellmax}}$ increases by scaling down the heads. When using metal implants the increase of $\text{SAR}_{1\text{cellmax}}$ is significant as it exceeds the value of 53 W/kg, and this value increases by 4% if the person wears glasses as well. Usually, the maximum SAR can be found on the surface of heads, however, in the case of metal implants it moves in the proximity of the plate. If the phone conversation is longer than 6 min the exposure exceeds the ANSI/IEEE general public limits for adults and children of 9–10 wearing glasses and having an implant.

If the models do not wear glasses or have no implants then the highest SAR value at 1800 MHz occurs in the case of children of 9–10 (0.125 W average radiation power, vertical phone position). The penetration of RF energy is lower than at 900 MHz. The position of maximum exposure point gets lower along the vertical axis of head. The RF power is also conducted by the metal implant. The glasses and implant causes higher exposure for adults, however, in the case of children of 9–10 a screening effect can be observed.

For 1800 MHz RF radiation, horizontally positioned phone, and adult model wearing glasses and implant the SAR increases by 20%. At children of 2–3 wearing implant, as well as both implant and glasses we may observe the so-called hot spots. The $\text{SAR}_{1\text{gmax}}$ and $\text{SAR}_{10\text{gmax}}$ values do not exceed the ANSI/IEEE (1992) and EC (1999) limits in neither case.
Figure 4. SAR distribution in the head of (a) adults, (b) children of 9–10, and (c) children of 2–3 for 900 MHz mobile phone ($P_{\text{av}} = 0.25$ W average radiated power, phone in horizontal position with metal framed glasses and without implant.

When 2100 MHz RF radiation is applied the SAR$_{1\text{cellmax}}$ is lower than at 1800 MHz radiation. The highest values have been obtained for children models with horizontally positioned phone and implant. The SAR distribution shows that 10 g averaged SAR values are always below the European standard limit; however, the ANSI/IEEE (1992) limits are exceeded in the case of the adult head model with a horizontally positioned phone.

**Summary**

The SAR distribution in scaled human heads (adult/children of 9–10/2–3) has been analyzed at 900/1800/2100 MHz frequencies. In several simulation setups, the models are provided with metal framed glasses and implants.

In general, the highest SAR values occur at children, which could be as much as 100% higher than for the adult head model. Comparing the results with the international standards we may conclude that:

- in the case of normal model (without implant) the 519/1999/EC limits are not exceeded,
- at 900 MHz for children model with metal implant and at 2100 MHz for adult head with vertically positioned phone the ANSI/IEEE might be exceeded.
The highest SAR value can be found at 900 MHz with vertically positioned phone, because the highest radiated power is applied at that frequency. The maximum exposure can be usually found at the surface of the head (outer surface of the ear). However, when using metal implant it moves to the proximity of plate. The SAR modification effect of the metal framed glasses is not significant. Our experiments show some phone positions, when the scattering of the metal is effective and the SAR decreases.

References


