Human Head Size and SAR Characteristics for Handset Exposure

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ABSTRACT— Using scaled models for an anatomical head model and a simple head model, we investigated the effects of head size on specific absorption rate characteristics for two mobile phones operating at 835 MHz and 1765 MHz. Our results showed that a larger head produced a higher localized SAR at 835 MHz. However, at 1765 MHz, the differences among the head models were insignificant since the superficial absorption was dominant over the effects of head shape and size. A larger head produced a lower whole-head averaged SAR at both frequencies.

I. INTRODUCTION

Studies on the differences in electromagnetic absorption between the heads of adults and children exposed to mobile phones or dipole sources at mobile communication frequencies [1]-[3] produced results which greatly differed from one study to another. The investigation in [1] reported a deeper penetration and significantly greater localized SAR in children's heads at 835 MHz while [2] and [3] found no significant differences. These studies used adult anatomical models with auricles and the models were volume-scaled, and [2] also used anatomical models for children obtained from MRI images. The voxel sizes for each scaled model were different from the original one in these studies, and the voxel sizes for the original models were also different from each other. The auricles and the different voxel sizes might have produced the inconsistent results in both papers. To discover the effects of head size and shape on electromagnetic absorption characteristics, our investigation used an anatomical model from which the auricles were removed (Model A) and a simple head model (Model B) in order to exclude the effect of the auricles on specific absorption rate (SAR) characteristics. We scaled both models and then, using the finite difference time domain method (FDTD) calculated SAR distributions for these models exposed to mobile phones operating at 835 MHz and 1765 MHz.

II. NUMERICAL MODELS

We used the FDTD method to obtain the electromagnetic field distributions in the head models. The same cell size of $\Delta x=\Delta y=\Delta z=2$ mm was used for the original model A, B, and all other scaled models, and the computational space containing the head and phone was truncated with the second order Mur absorbing boundaries for all cases.

We implemented a new head model based on magnetic resonance (MR) and computerized tomography (CT) images of a volunteer whose head shape was very close to the domestic (Korean) standard for the 18-24 age group. Table 1 gives the physical measurements of the models. The auricles of the original model were removed. This model (Model A) was scaled by volume to five different head sizes with the size being 90, 95, 100, 105, and 110% of the original model. The Federal Communications Commission (FCC) data were used for the electrical properties such as dielectric constant and conductivity of each tissue type [4].

To investigate the tendency in SAR distributions more accurately, we implemented a simple head model (Model B) with the domestic standard sizes of head length, head breadth, and chin-vertex length. It was scaled by 5% steps from 80% to 120% for four different cases: head length only, head breadth only, chin vertex length only, and volume (all three parameters simultaneously).

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We simulated these simple models with homogeneous tissue properties: εr (dielectric constant) = 55.192 and σ (conductivity) = 0.921(S/m) at 835 MHz, εr = 55.386 and σ = 1.417 at 1765 MHz, and ρ (mass density) = 1040 (kg/m3).

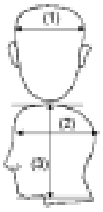
The outer size and antenna length of the numerical phone model were 108×46×22 mm and 64 mm for 835 MHz, and 100×44×24 mm and 44 mm for 1765 MHz. These sizes were approximately those of typical mobile phones. At 835 MHz, the antenna was 18 mm away from the phone surface facing the head model's cheek, and at 1765 MHz, it was 20 mm. The plastic casing was simulated with a dielectric insulator with εr=4.0 and a thickness of 2 mm. The antenna was fed using the well-known coaxial feeding method. The time-averaged radiated power of each phone was 300 mW. For both of the head models, the phone was located on the reference plane defined by the three points of the two auditory canal openings and the tip of the mouth. As the test position of the phone, the touch position was used for the anatomical models, and the phone was directed parallel to the sagittal plane of the head for the simple models, as shown in Fig. 1 [4], [5].

III. RESULTS AND DISCUSSION

Depending on the mass-averaging method, the maximum localized SAR value can vary widely. The recently proposed method for extracting a cubic tissue produces different SARs according to the air contents of the averaged tissue [6]. A lower air content produces a tissue volume closer to the cube but underestimates local SAR results. Thus, this method cannot take into account the irregular surface of a human body. We used the contiguous volume technique suggested in [7] to obtain the mass-averaged SAR. This averaging technique sums the node masses of FDTD cells enclosing a calculation point until the mass gets closest to the required mass. Therefore, at the skin layer and in the tissue region around the sinuses such as the nasal cavities, this volume follows the exact tissue shape in the region of interest.

Table 1. Comparison of physiques of the simulated models [unit: mm].

	Model A (Volunteer)	Model B (Domestic standard)
(1) Head breadth	160	158
(2) Head length	187	181
(3) Chin-vertex length	229	232



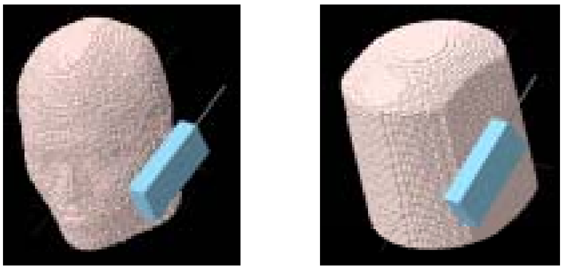

(a) Model A
(b) Model B

Fig. 1. Test positions.

Figures 2, 3, and 4 give our calculated results. For five scale factors of Model A, the 10 g averaged SAR and whole-head averaged SAR showed specific trends but a part of the peak and 1 g-averaged SARs produced inconsistent results due to superficial irregularities of the anatomical head rather than the head shape. The cross-sectional views in Fig. 2 are the 10 g averaged SAR distributions in the plane including the nasal cavities and the phone antenna for Model A. In a larger head, a higher local SAR appears at 835 MHz. At 1765 MHz, the differences of the local SARs among the head models are relatively insignificant since the superficial absorption is dominant compared with the effect of head size, which is electrically larger. Figure 2 suggests that the head volume-averaged SAR decreases with an increasing head size, considering that RF attenuation by tissue is dependent on frequency, although the absorbed power in the head increases. Figure 3 demonstrates this estimation for Model A and Model B.

The local SAR results of Fig. 4 show the trend more clearly and in detail. The results for all cases except head breadth variation for Model B at 835 MHz support the conclusion that a larger head produces a higher local SAR and a lower whole head-averaged SAR. However, at 1765 MHz, the local SAR differences between the scaled models are very slight. This suggests that when the frequency is higher, the effect of the

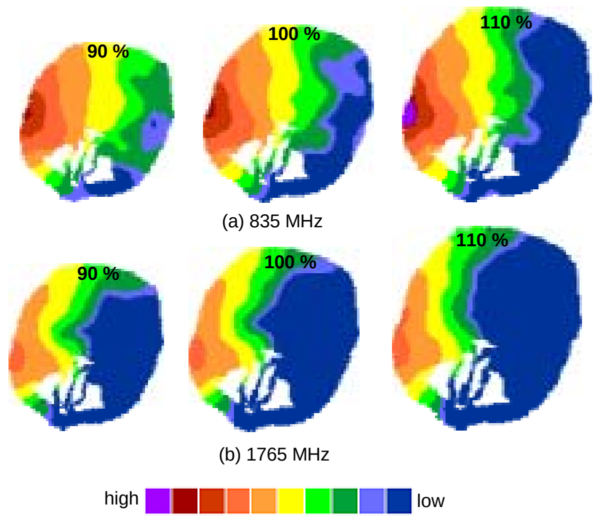


Fig. 2. 10 g averaged SAR distributions for Model A.

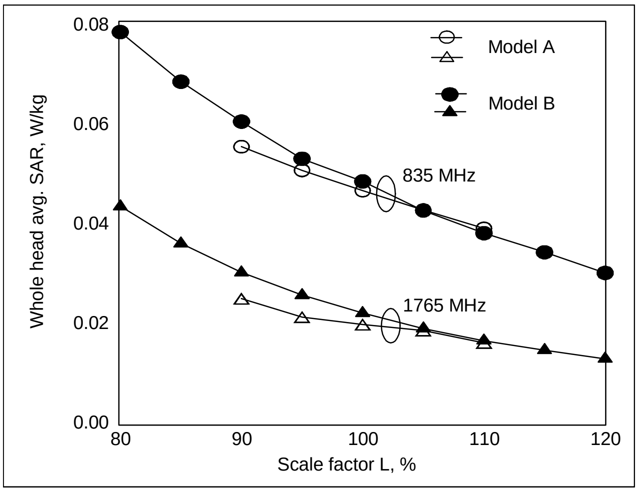


Fig. 3. Whole-head averaged SAR results.

head shape on the local SAR grows weaker and superficial absorption is the primary factor for the SAR result.

IV. CONCLUSIONS

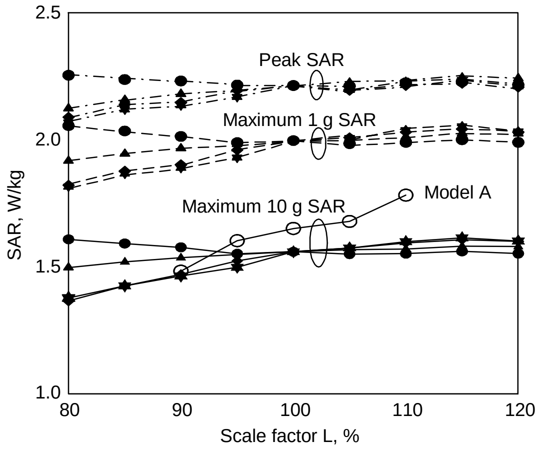
This paper investigated the effect of head size on SAR characteristics using an anatomical model and a simple model exposed to mobile phones operating at 835 and 1765 MHz. The major findings are summarized as follows:

1) A deeper EM energy penetration into a head occurs at 835 MHz than at 1765 MHz,

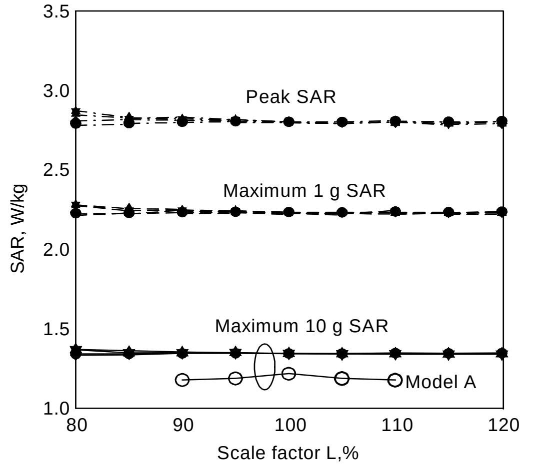
2) At the both frequencies, a larger head produces a lower whole-head averaged SAR, and

3) Head geometry strongly influenced the localized SAR evaluation at 835 MHz and we observed a trend of increasing localized SAR for a larger model. At 1765 MHz, however, head geometry was no longer a factor influencing the localized SAR and the maximum local SAR results were constant.

At present, most measurement standards including those of the FCC and CENELEC describe SAR evaluation methods only for a large adult phantom head model. The large head model produces a higher localized absorption. The FCC and CENELEC consider the large head model to be the desirable condition for SAR compliance tests of mobile phones. Our results support this. However, in compliance tests of mobile phones only localized SAR values are used, and safety guidelines for radio frequencies are based on the critical whole-body averaged SAR at which absorbed EM energy causes adverse health effects such as heat exhaustion and heat stroke. Therefore, a greater whole-head averaged SAR in a smaller head model should be properly taken into account. In addition, our results can be used to investigate differences of EM absorption levels in heads according to different races and ages.



(a) 835 MHz



(b) 1765 MHz

Symbols for Model B are as follows.
● L=(1)(mm)/158, ((2):181 mm, (3):232 mm).
◆ L=(2)(mm)/181, ((1):158 mm, (3):232 mm).
▲ L=(3)(mm)/232, ((1):158 mm, (2):181 mm).
★ L=(1)(mm)/158=(2)(mm)/181= (3)(mm)/232.

Fig. 4. Local SAR values.

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