Correlation between Peak Spatial-Average SAR and Maximum Temperature Increase Due to Dipole Antenna in the Frequency Range 1-10 GHz

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INTRODUCTION

International and domestic organizations have established safety guidelines for human protection against EM wave exposure. For RF near field exposure, these guidelines are based on spatial peak SAR (specific absorption rate) for any 1 or 10g of body tissue. Incidentaly, note that a different averaging scheme is used for each guideline. However, physiological effects and damage to humans by EM wave exposures are induced by temperature increases. A temperature increase of 4.5 ^{o}C in the brain has been noted to be an allowable limit which does not lead to any physiological damage (for exposures of more than 30 minutes). Additionally, the threshold temperature for pricking pain in skin is 45 ^{o}C, corresponding to the temperature increase of 10-15 ^{o}C. In view of these circumstances, the temperature increase in the anatomically-based human head model due to handset antennas has been calculated in several works (e.g., [1]-[3]). Particularly, we have revealed that maximum temperature increases in the head and brain are reasonably proportional to peak SARs in these regions [4]. The frequency band considered was from 900 MHz to 2.5 GHz, which are assigned to cellular telephones.

The fourth generation mobile cellular system will be deployed around the year 2010. The most promising frequency band for this system is 4 to 5 GHz band. The frequency band assigned for wireless LAN is at 5.8 GHz. It is instructive to investigate correlation between maximum temperature increase and peak spatial-average SAR in frequency bands which cover such emerging wireless technologies. Then, our attention is extended to the frequency band from 1 to 10 GHz. Firstly, by using one-dimensional model, we discuss uncertainty of tissue composition [5] on this correlation. Next, three-dimensional cubic model is used to investigate the effect of antenna dimension on the correlation. SAR averaging schemes prescribed in the ICNIRP guideline [6] and IEEE standard [7] are considered in this paper.

COMPUTATIONAL METHODS AND MODEL

Two scenarios are treated in this paper. Firstly, a seven-layered one-dimensional model [5] is considered to discuss the uncertainties caused by tissue inhomogeneity. Then, a three-dimensional cubic model is considered for discussing the effect of finite dimension of an antenna. For both scenarios, computation for deriving the correlation is conducted in two steps. As the first step, the SAR in the model is calculated with the use of the FDTD method. Then, the temperature rise is calculated by substituting SAR values obtained into the bio-heat equation. The thermal parameters in [2] are used in this paper.

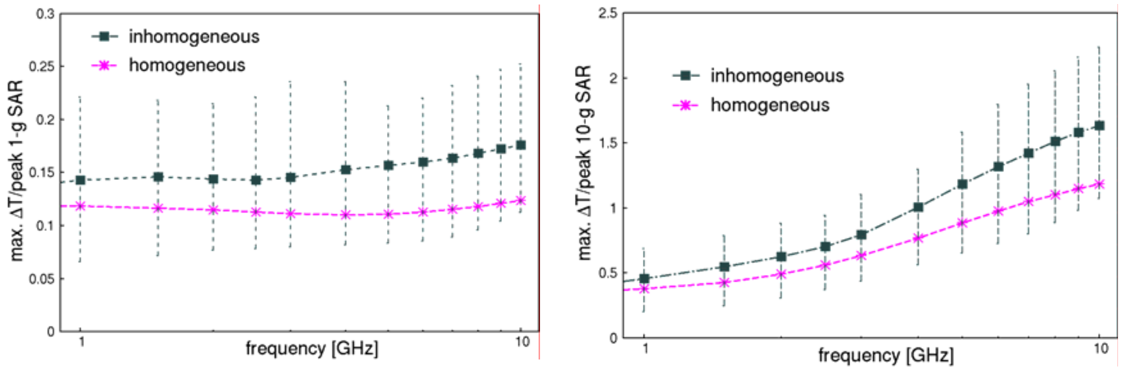
COMPUTATIONAL RESULTS

Figure 1 shows the frequency dependency of the ratio of maximum temperature increase to peak SAR averaged over 1g (a) and 10g (b) tissues for the one-dimensional model. The error bars for inhomogeneous model represent uncertainty caused by tissue composition. Since we consider the one-dimensional model, peak 1g and 10g SARs are defined as the SAR averaged over 10 mm and 22 mm thicknesses. As seen from this figure, the correlation between peak SAR and maximum temperature increase is dependent on the frequency. Comparing Figs. 1 (a) and (b), the correlation for the averaging mass of 1g is less sensitive to the frequency than that for the mass of 10g. The reason for this difference can be explained as follows. With the increase in the frequency, EM power absorption concentrates around the surface of the model, which is attributed to the increase of tissue conductivity. Now the averaging thickness is fixed, peak 10-g SAR increases moderately with the increase of the frequency. Maximum temperature increase also becomes large in accordance with the increase of peak SAR. Note that maximum temperature increase is not proportional to peak SAR, which is caused by heat conduction. The balance of increases between peak SAR and maximum temperature increase determines the frequency characteristics of the temperature increase and SAR.

Next, the effect of finite dimensions of an antenna is discussed using a cubic model, whose side length is 200 mm. Frequency dependency of the ratio of maximum temperature increase to peak SAR averaged over 1g and 10g tissues for cubic model is presented in Fig. 2. The curves for the one-dimensional model are also plotted in this figure for comparison. The values for the cubic model are smaller than those of 1-D model. The decrease of the maximum temperature increase divided by peak SAR becomes obvious at high frequencies. Additionally, the difference between 1-D and 3-D results is significant for the averaging mass of 10g. This is attributed to the finite dimension of the antenna. Namely, the contribution of SAR outside the averaging volume to maximum temperature increase is small at higher frequencies. Due to the balance between the effect of the penetration depth and antenna dimension, the maximum temperature increase divided by peak SAR for 10-g mass is less dependent on the frequency than for 1-g mass.

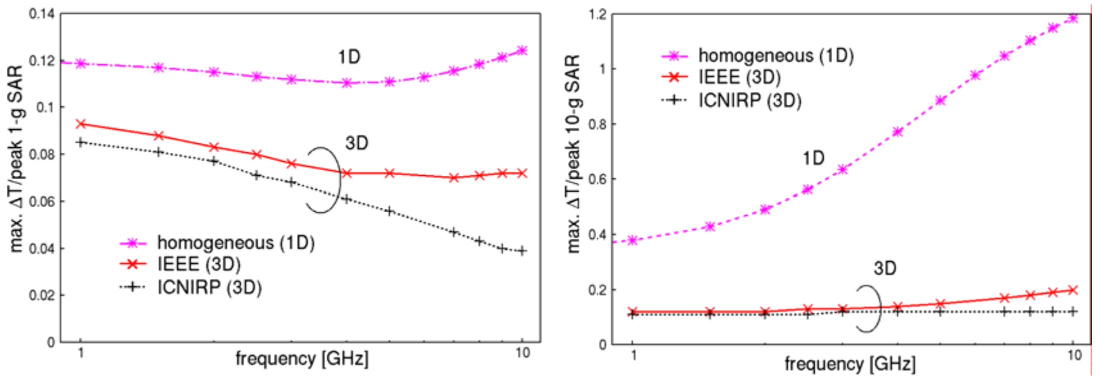
SUMMARY

This paper presented preliminary results for the correlation between peak spatial-average SAR and maximum temperature increase in the head model for the frequency band of 1-10 GHz. In future work, the effect of pinna on this correlation will be discussed. In the final step, the correlation for 3-D realistic model will be derived.



(a) (b)

Figure 1: Frequency dependency of the ratio of maximum temperature increase to peak SAR averaged over 1g (a) and 10g (b) tissues for one-dimensional model.



(a) (b)

Figure 2: Frequency dependency of the ratio of maximum temperature increase to peak SAR averaged over 1g (a) and 10g (b) tissues for cubic model.

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