IEICE TRANS. COMMUN., VOL.E91–B, NO.11 NOVEMBER 2008

LETTER

Effect of Heterogeneity of Tissues on RF Energy Absorption in the Brain for Exposure Assessment in Epidemiological Studies on Mobile Phone Use and Brain Tumors

Nadege VARSIER[†,††a)], ***Nonmember***, **Kanako WAKE**[††], **Masao TAKI**[†,††], ***and*** **Soichi WATANABE**[††], ***Members***

SUMMARY We compared SAR distributions in major anatomical structures of the brain of a homogeneous and a heterogeneous model using FDTD calculations. Our results proved a good correlation between SAR values in lobes of the brain where tumors may arise more frequently. However SAR values at some specific locations were shown to be under or overestimated.

key words: *brain, epidemiological study, health effects, RF exposure, SAR*

1. Introduction

The increasing use of mobile phones over the last 15 years has focused attention on possible effects of radiofrequency (RF) exposure. An international collaborative epidemiological study called INTERPHONE [1] was conducted to evaluate the possible relationship between the risk of brain tumors and electromagnetic field (EMF) exposure from mobile phones; Japan was one of the countries in the study [2], [4].

Studies were conducted focusing on the estimation of the specific absorption rate (SAR) at the specific location of tumors [1], [3]–[5]. They were based on SAR measurements performed originally for compliance testing [3]–[5], which raised the question of the consistency of using measurements performed in a homogeneous phantom to estimate SAR in the brain of a heterogeneous model.

The study tries to answer to this question by evaluating the correlation, using Finite-Difference Time-Domain (FDTD) simulations, between SAR values in the brain of a homogeneous and a heterogeneous model and comparing SAR distributions and relative average SAR values in different major anatomical locations in the brain of the two numerical models.

2. Material and Method

2.1 Numerical Head Model

For the purpose of our study we used the head part of the Japanese numerical heterogeneous model TARO. It is a whole-body numerical voxel model which was developed using MRI data from a Japanese adult male [6]. It is originally a 2-mm resolution model and it has been segmented into 51 tissues. We used the head part (23 tissues), modified from the original model to a 1-mm resolution model. This numerical heterogeneous model was chosen because it was the one used in the Japanese epidemiological study [3], [4]. Figure 1 shows sagittal cuts, acquired every 1 cm, representing the left half part of TARO head.

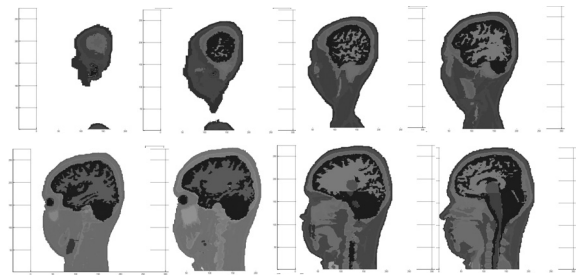

Fig. 1 Sagittal cuts representing the left half part of TARO head.

2.2 Anatomical Structures of TARO Model Brain

In order to evaluate SAR distributions in different anatomical locations in the brain, the left half part of the brain of numerical model TARO was mapped by different IDs identifying major anatomical structures of the brain using 1-cm resolution cubes: temporal (340 cubes), parietal (191 cubes), frontal (352 cubes) and occipital (96 cubes) lobes, cerebellum (123 cubes) and brain stem (81 cubes). The 1-cm resolution was the one used in INTERPHONE study to localize brain tumors [1]. Figure 2 represents a surface view of the left half part of the brain of TARO, with specific anatomical structures highlighted by different colours.

2.3 FDTD Simulation Conditions

FDTD simulations were run using the FDTD simulator Poynting (Fujitsu) to calculate SAR distributions in homogeneous and heterogeneous TARO model heads. Figure 3 summarizes the conditions of simulations. A simple phone model consisting of a metal box and a quarter wavelength monopole antenna at 835 MHz was placed near the head in

Manuscript received March 24, 2008.
Manuscript revised June 24, 2008.
[†]The authors are with Tokyo Metropolitan University, Hachioji-shi, 192-0397 Japan.
[††]The authors are with the National Institute of Information and Communications Technology, Koganei-shi, 184-8795 Japan.
a) E-mail: nadege@nict.go.jp
DOI: 10.1093/ietcom/e91–b.11.3792

Copyright © 2008 The Institute of Electronics, Information and Communication Engineers

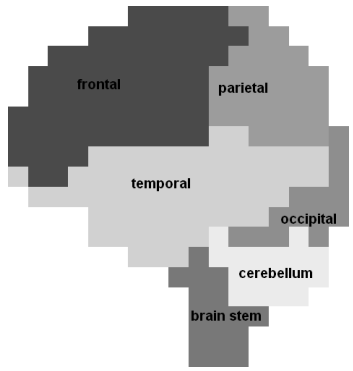

Fig. 2 Surface view of TARO left hemisphere of the brain.

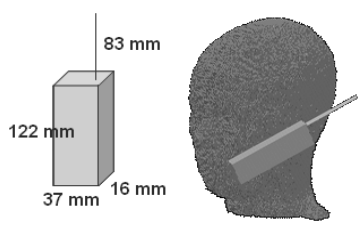

Fig. 3 Exposure conditions for FDTD calculations.

cheek position [7] on the left side. The mesh size of FDTD calculation was 1 mm and Perfectly Matched Layer (PML) were applied as absorbing boundary conditions. The size of the region was $400 \times 400 \times 400\,\mathrm{mm}^3$. The antenna input power was 1 W.

FDTD calculations were performed for the homogeneous ($\varepsilon_r = 39.425$, $\sigma = 0.855$ [S/m], $\rho = 1000$ [kg/m^3]) and the heterogeneous TARO models (tissue dielectric properties given by Gabriel's report [8]).

3. Results and Discussion

3.1 Correlation of SAR Distributions in the Brain of Homogeneous and Heterogeneous Models

We compared first SAR distributions in the brain at the resolution of 1 cm.

We calculated the correlation and the regression coefficients between 1 cm-cube SAR values in the brain of the homogeneous and the heterogeneous TARO. Table 1 lists the calculated correlation and regression coefficients. Figure 4 shows a scatter diagram of SAR values in the heterogeneous TARO versus SAR values in the homogeneous TARO. Figure 5 represents the surface view of 1cm-cube SAR distributions in the brain for heterogeneous and homogeneous models, respectively.

Though we can remark a few values differing from more than 30%, the calculated correlation coefficient of 0.93 between SAR values in the brain for homogeneous and heterogeneous models showed a generally good agreement and proved that it is reasonable to use data obtained in a homogeneous phantom to estimate SAR in the brain of a heterogeneous model at a spatial resolution of 1 cm. We could expect this good correlation considering the 1-cm resolution as well as the fact that only the brain part is considered in this study. The correlation might not be so good if considering the whole head.

Table 1 Correlation and regression coefficients between SAR values in the brains of heterogeneous and homogeneous TARO models.

Correlation coefficient	Regression coefficient (95% CI)*
0.93	1.004 (0.988– 1.021)

*Values in heterogeneous model versus values in homogeneous model.

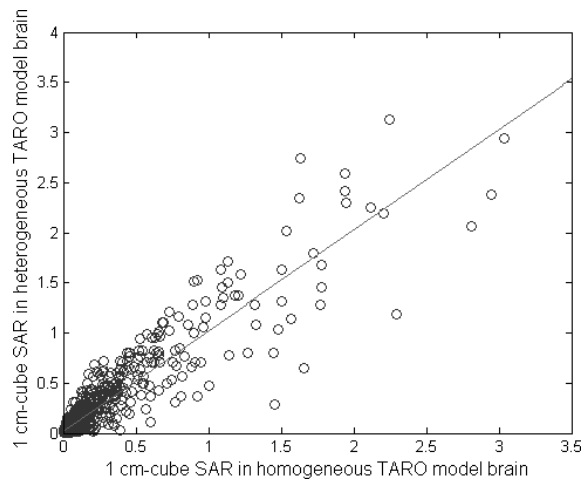

Fig. 4 Scatter diagram of 1 cm-cube SAR [in W/kg] distributions in the brain of the homogeneous TARO and the heterogeneous TARO models.

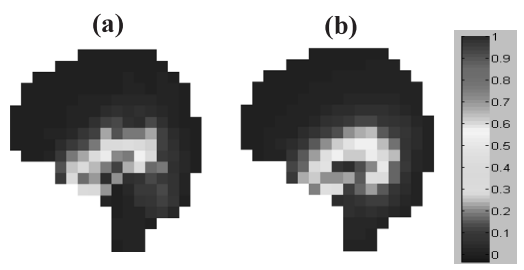

Fig. 5 Surface views of 1 cm-cube SAR distributions in the left brain hemisphere (SAR values normalized by the maximum SAR value in the brain) for, respectively, heterogeneous (a) and homogeneous (b) models.

Moreover the regression coefficient of 1.0 proved that SAR values in the brain of the heterogeneous model, using 1-cm resolution, are neither overestimated nor underestimated compared to values in the brain of the homogeneous one.

Brain tumors may occur more often at some specific locations in the brain and if the correlation coefficient in the brain was quite good, some under or overestimation may occur at some specific location. We therefore calculated correlation and regression coefficients between SAR values in different anatomical locations (cf. Fig. 2) in the brains of homogeneous and heterogeneous TARO models (see Table 2).

We observe in Table 2 that correlation coefficients are quite good for temporal, parietal and frontal lobes. Brain

Table 2 Correlation and regression coefficients between SAR values in the different brain structures of homogeneous and heterogeneous TARO models — *in the left half of the brain, for a phone held on the left side.*

Structure	Half brain	Temporal lobe	Frontal lobe	Parietal lobe	Occipital lobe	Cerebellum	Brain stem
Number of 1-cm cubes	1183	340	352	191	96	123	81
Correlation coefficient	0.925	0.92	0.95	0.94	0.78	0.75	0.23
Regression coefficient (95% CI)*	0.99 (0.967 – 1.013)	0.96 (0.914 – 1.002)	1.37 (1.326 – 1.42)	1.19 (1.13 – 1.25)	0.43 (0.357 – 0.497)	0.55 (0.466 – 0.643)	0.099 (0.003 – 0.19)

*Values in heterogeneous model versus values in homogeneous model.

tumors arise mostly in these lobes [9] and the temporal lobe is where most of RF energy absorption occurs [5]. The fact that SAR values in these specific lobes are well correlated is therefore an important observation for exposure assessment purpose in epidemiological studies. SAR values were found less correlated in the occipital lobe, the cerebellum and especially in the brain stem. The occipital lobe and the cerebellum structures are smaller structures compared to the temporal, frontal and parietal lobes, which can explain partly the poorer correlation coefficients. The fact that the cerebellum and the occipital lobe, in the heterogeneous model, may be "protected" by thicker bones at the back of the head may also be one explanation [10]. For the brain stem, we are comparing few values and small values (maximum SAR is inferior to 13% of the maximum value in the brain) so that is why we obtained a very poor correlation coefficient.

The regression coefficients show a marked tendency to overestimate SAR values in the frontal and the parietal lobes for the heterogeneous model whereas values in the occipital lobe, the cerebellum and the brain stem are clearly underestimated. This could be partly explained by the consideration of internal air in the heterogeneous model and, one more time, by thicker bones at the back of the head.

3.2 Comparison of Relative Average SAR Values in Different Anatomical Locations in the Brain of Homogeneous and Heterogeneous Models

INTERPHONE study conducted an analysis evaluating the distribution of RF energy emitted by mobile phones in the major anatomical structures of the brain [5]. Measurements were used to estimate relative average SAR values in different anatomical structures of a heterogeneous model [5]. It was therefore important to compare the relative average SAR values in the homogeneous and heterogeneous TARO models at the different anatomical locations to analyze any possible under or overestimation, especially considering the results obtained in the previous section. Average SAR values in each anatomical structure were obtained by averaging over all the cubes in the specific location. Table 3 shows the distribution of the relative average SAR expressed as % of the maximum 1 cm-cube SAR value in the brain.

Table 3 Distribution of the relative average SAR expressed as % of the maximum 1 cm-cube SAR value in the brain — *in the left half of the brain, for a phone held on the left side.*

	Relative average SAR	
Structure	Heterogeneous model	Homogeneous model
Temporal	15.4%	13%
Frontal	1.2%	0.7%
Parietal	2.1%	1.6%
Occipital	2.1%	2.6%
Cerebellum	4.2%	4.6%
Brain stem	1.5%	2.8%

As already suggested by the calculated regression coefficients in the previous section, relative average SAR values in the cerebellum, in the occipital lobe and the brain stem for the heterogeneous model are a little bit underestimated while values in the temporal, frontal and parietal lobes are a bit overestimated.

4. Conclusion

We compared SAR distributions in the brain of a homogeneous numerical model and a heterogeneous numerical model exposed to near-field from a mobile phone using FDTD simulations.

We found that SAR values in the temporal, parietal and frontal lobes are well correlated whereas correlation coefficients were found to be quite poor for occipital lobe, cerebellum and brain stem. As most of RF energy absorption occurs in the temporal lobe as shown in [5] and brain tumors develop more frequently in the temporal, frontal and parietal lobes [9], we proved that it was quite reasonable to use SAR values measured for compliance testing to estimate SAR in the brain of a heterogeneous model for exposure assessment purpose in epidemiological studies. However the regression coefficients demonstrated a tendency to under or overestimate SAR values in some specific locations in the brain. Therefore these results should be used to moderate any conclusion on the exposure of the brain to EMF from mobile phones, especially any conclusion on cerebellum, occipital lobe and brain stem exposure levels as SAR values in these structures were found poorly correlated.

Finally it should be noted that the study was done us-

ing a simple mobile phone model. We could expect some consistencies of the results using more complicated phone models, like those with internal antenna, but we have no evidence and other cases should be also examined.

Acknowledgments

This work was partially supported by the Committee to Promote Research on the Possible Biological Effects of Electromagnetic fields from the Japanese Ministry of Internal Affairs and Communications.

References

[1] E. Cardis, L. Richardson, I. Deltour, B. Armstrong, M. Feychting, C. Johansen et al., "The INTERPHONE study: Design, epidemiological methods, and description of the study population," Eur. J. Epidemiol., vol.22, no.9, pp.647–664, 2007.

[2] T. Takebayashi, S. Akiba, Y. Kikuchi, M. Taki, K. Wake, S. Watanabe, and N. Yamaguchi, "Mobile phone use and acoustic neuroma risk in Japan," Occup. Environ Med., vol.63, pp.802–807, 2006.

[3] K. Wake, S. Watanabe, and M. Taki, "Estimation of 3D SAR distributions from mobile phone compliance testing data for the local exposure assessment in epidemiological study," URSI XXVIIIth General Assembly, New-Delhi, India, KAE.5, Oct. 2005.

[4] T. Takebayashi, N. Varsier, Y. Kikuchi, K. Wake, M. Taki, S. Watanabe, S. Akiba, and N. Yamaguchi, "Mobile phone use, exposure to radio frequency electromagnetic field and brain tumour: A case-control study," British Journal of Cancer, vol.98, pp.652–659, 2008.

[5] E. Cardis, I. Deltour, S. Mann, M. Moissonnier, M. Taki, N. Varsier, K. Wake, and J. Wiart, "Distribution of RF energy emitted by mobile phones in anatomical structures of the brain," Physics in Medicine and Biology, vol.53, pp.2771–2783, 2008.

[6] T. Nagaoka, S. Watanabe, K. Sakurai, E. Kunieda, S. Watanabe, M. Taki, and Y. Yamanaka, "Development of realistic high-resolution whole-body voxel models Japanese adult male and female of average height and weight and application of models to radio-frequency electromagnetic-field dosimetry," Physics in Medicine and Biology, vol.49, pp.1–15, 2004.

[7] IEC/EN 62209-1, "Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices - Human models, instrumentation, and procedures — Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)," 2005.

[8] C. Gabriel, "Compilation of the dielectric properties of body tissues at RF and microwave frequencies," Report N.AL/OE-TR- 1996-0037, Occupational and environmental health directorate, Radiofrequency Radiation Division, Brooks Air Force Base, Texas (USA), June 1996.

[9] The Committee of Brain Tumor Registry of Japan, "Report of brain tumor registry of Japan (1969–1996)," 11th ed., Neurologia Medico-Chirurgica, vol.43, Supplement, 2003.

[10] V.G. Dimopoulos, I.Z. Kapsakalis, and K.N. Fountas, "Skull morphology and its neurosurgical implications in the Hippocratic era," Neurosurgical Focus, vol.23, no.1, p.E10, 2007.