Effects of Size and Permittivity of Rat Brain on SAR Values at 900 MHz and 1,800 MHz

Jong-Chul Hyun · Yisok Oh

Abstract

The objective of this study is to evaluate the effects of size and permittivity on the specific absorption rate(SAR) values of rat brains during microwave exposure at mobile phone frequency bands. A finite difference time domain (FDTD) technique with perfect matching layer(PML) absorbing boundaries is used for this evaluation process. A color coded digital image of the Sprague Dawley(SD) rat based on magnetic resonance imaging(MRI) is used in FDTD calculation with appropriate permittivity values corresponding to different tissues for 3, 4, 7, and 10 week old rats. This study is comprised of three major parts. First, the rat model structure is scaled uniformly, i.e., the rat size is increased without change in permittivity. The simulated SAR values are compared with other experimental and numerical results. Second, the effect of permittivity on SAR values is examined by simulating the microwave exposure on rat brains with various permittivity values for a fixed rat size. Finally, the SAR distributions in depth, and the brain-averaged SAR and brain 1 voxel peak SAR values are computed during the microwave exposure on a rat model structure when both size and permittivity have varied corresponding to different ages ranging from 3 to 10 weeks. At 900 MHz, the simulation results show that the brain-averaged SAR values decreased by about 54 % for size variation from the 3 week to the 10 week-old rat model, while the SAR values decreased only by about 16 % for permittivity variation. It is found that the brain averaged SAR values decreased by about 63 % when the variations in size and permittivity are taken together. At 1,800 MHz, the brain-averaged SAR value is decreased by 200 % for size variation, 9.7 % for permittivity variation, and 207 % for both size and permittivity variations.

Key words : Specific Absorption Rate, Size and Permittivity of Rat Brain.

Ⅰ. Introduction

Specific absorption rate(SAR) variations according to size, shape, and user age have been widely studied because of the controversy about children being more adversely affected than adults by electromagnetic field (EMF) exposure from using mobile phones. It was reported by the independent expert group on mobile phones(IEGMP) in England that children may be more vulnerable to unrecognized adverse health effects from the use of mobile phones because of their developing nervous system, the greater absorption of energy in the tissues of their head, and a longer lifetime of exposure than adults[1].

The dosimetric analysis of rat brain has been of great importance to simulate human head exposure to microwaves, especially at mobile phone frequencies[2],[3]. Recently, experimental and numerical studies have been reported on the SAR variation of different sizes of rats [4],[5]. It was reported that the brain-averaged SAR decreases as the rat size increases[4]. However, it was shown that the measured whole body-averaged SAR tends to increase as the rat size increases for anesthetized rats, while the SAR values decrease as the rat size increases for rat cadavers, phantoms and models[5].

The dielectric constant and conductivity of a rat may vary, as well as its size, according to the variation in age, while the dielectric constant and conductivity are supposed to affect the SAR value significantly. In this study, the brain-averaged SAR values as well as the SAR distribution in depth have been computed for various sizes, dielectric constants, and conductivities. In addition, the sensitivity of SAR on the size and permittivity of rat brains exposed to EMF was evaluated using the FDTD method. We used the appropriate values of dielectric constants and conductivities corresponding to animal sizes/weights based on the data given in [6], which provide the permittivity values for 10 organs for six different ages, i.e., from newborn to 70 days in the frequency range of 130 MHz to 10 GHz. The size data were obtained from the measurements of rats according to four different ages ranging from three to ten weeks. The SD rat model for FDTD calculation was constructed from MRI color-coded slice images as in [7].

Manuscript received October 26, 2005 ; revised February 2, 2006. (ID No. 20051026-043J)

Department of Radio Science and Communication Engineering, Hongik University, Seoul, Korea.

Ⅱ. Numerical Modeling

The SAR values of the SD rats were computed numerically using an FDTD code with PML absorbing boundaries. At first, the FDTD code was verified through the computation results for the radar cross section (RCS) of a conducting cylinder, and comparison with the high frequency structure simulator(HFSS). Then the code was used to compute the SAR values of the SD rat which was modeled using color-coded digital images based on MRI data as in [7]. A rectangular 3×1 cm folded dipole antenna as a microwave source was positioned 5 mm above the center of rat head for all ages as shown in Fig. 1. The antenna was designed using the NEC design tool to have an optimum performance with the thickness of one cell.

The electric field of each voxel was computed in the time domain using the FDTD time-marching process, and the time domain responses were time-averaged to get the electric field values at 900 MHz and 1800 MHz. Then the SAR values were computed using the electric field, the density, and the conductivity of each voxel of the model. Each simulation process took about 12 hours on a personal computer with a 2.8 GHz CPU and a 2 GB RAM.

The rats' size data were obtained by measurements of 3, 4, 7, and 10-week old SD rats as shown in Table 1.

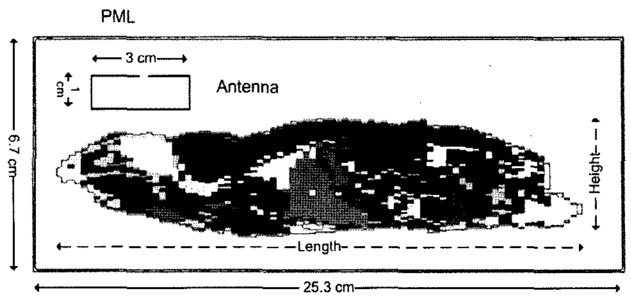


Fig. 1. A cross-section view of a digital image of a 10-week SD rat.

Table 1. Rat size and resolution for each age.

Age (week)	Length (cm)	Height (cm)	Head Width (cm)	Body Width (cm)	Resolution (x×y×z) (mm)
3	12	2.8	2.0	4.8	0.27×0.31×0.5
4	15	2.9	2.3	5.7	0.31×0.32×0.625
7	21	3.5	2.6	7.0	0.35×0.4×0.875
10	24	3.6	3.0	8.8	0.4×0.4×1.0

We took one rat for each age for this measurement assuming the rats well represent the ages. The resolutions of the color-coded digital models, which were obtained from the size data, are also shown in Table 1. In order to examine the effect of the cell size on the simulation, the field absorption into a dielectric sphere with a dipole antenna was simulated. It was found that the effect of the cell size was negligible in our simulations. For example, the SAR values for a dielectric sphere with radius of 9 mm in front of the antenna with the cell size of 0.50×0.50×0.50 mm and 0.60×0.60×0.60 mm are 199.4 and 196.1, respectively, which gives only 1.7 % change of SAR value for the cell size variation.

The tissue parameters, such as dielectric constant and conductivity, were obtained from the 4 ColeCole analysis at 900 MHz at 1,800 MHz using the calculation board given in the FCC web site[8]. The tissue parameters for different ages were derived from the data given in [6]. Both the dielectric constant and the conductivity of SD rat tissues decreased as rat's age increased. The decreasing rate was rapid, especially for skull tissues. The dielectric constants and conductivities for the brain(both grey and white matter), muscle, skull, skin, tongue, liver, spleen and kidney appeared to change according to age variation as shown in Tables 2 and 3, because the nine tissues may affect mostly the

Table 2. Dielectric constants and conductivities of 9 different tissues for 5 different ages at 900 MHz.

	2 week		3 week		4 week		7 week		10 week	
	ε	σ	ε	σ	ε	σ	ε	σ	ε	σ
Grey matter	64.46	1.29	58.28	1.14	54.94	1.06	51.01	0.96	48.57	0.90
White matter	47.64	0.81	43.07	0.71	40.61	0.66	37.70	0.60	35.90	0.57
Muscle	67.55	1.28	62.64	1.16	59.93	1.09	56.69	1.01	54.65	0.96
Skull	22.31	1.15	20.66	1.10	18.42	1.05	17.78	0.97	12.45	0.59
Skin	53.99	1.37	48.75	1.24	45.93	1.16	42.60	1.06	40.54	0.85
Tongue	60.84	1.02	51.14	0.84	47.50	0.84	51.04	0.84	53.56	0.93
Liver	49.39	0.96	49.39	0.96	49.17	0.85	46.94	0.85	46.83	0.85
Spleen	63.46	1.55	63.47	1.55	62.00	1.55	59.19	1.41	57.18	1.27
Kidney	62.82	1.54	62.83	1.55	64.70	1.39	61.48	1.39	58.68	1.39

Table 3. Dielectric constants and conductivities of 9 different tissues for 5 different ages at 1,800 MHz.

	2 week		3 week		4 week		7 week		10 week	
	ε	σ	ε	σ	ε	σ	ε	σ	ε	σ
Grey matter	64.69	1.84	58.45	1.64	55.09	1.54	51.12	1.41	48.67	1.34
White matter	50.23	1.19	45.39	1.06	42.78	0.99	39.70	0.91	37.79	0.86
Muscle	66.37	1.66	61.41	1.56	58.69	1.50	55.42	1.43	53.37	1.38
Skull	21.45	0.52	19.99	0.44	17.30	0.41	17.45	0.39	11.78	0.27
Skin	50.95	1.50	45.95	1.36	43.25	1.29	40.07	1.20	38.11	1.15
Tongue	60.43	1.56	52.10	1.24	46.87	1.21	51.68	1.26	53.56	1.37
Liver	46.62	1.45	46.62	1.45	46.42	1.28	44.3	1.28	44.21	1.28
Spleen	59.77	2.17	59.77	2.17	58.39	2.17	55.73	1.97	53.84	1.77
Kidney	58.27	2.16	58.27	2.16	60.01	1.94	57.03	1.94	54.42	1.94

SAR values of the brain, among others.

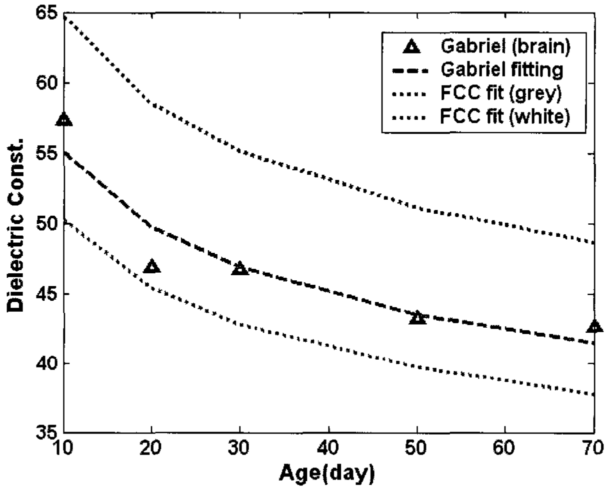
As regards the brain, its structure has two parts, i.e., the white matter and the grey matter. The permittivity value of the brain were reported in [6] for different ages without separation between the white matter and the grey matter, while the FCC gives the values of both the white matter and the grey matter without information for age variation. So we scaled the two different brain FCC permittivity values by data-fitting Gabriel's values in [6] as shown in Figs. 2(a) and (b).

Ⅲ. Computation Results

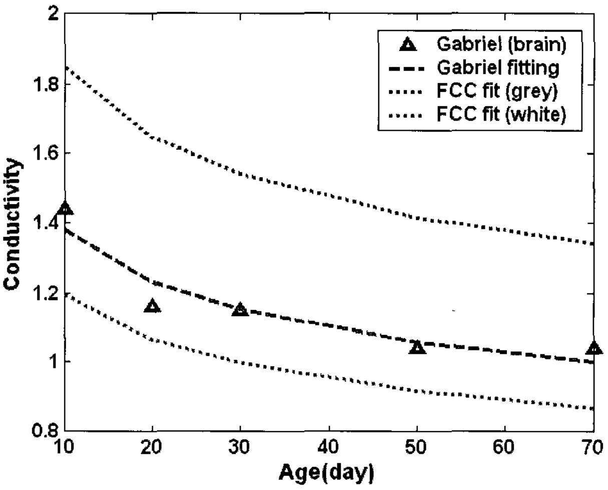
The FDTD method was used to simulate the SAR distribution in the rat's brain for three different cases, i.e., size variation, permittivity variation, and both size and permittivity variation, to find out how much rat size and permittivty variations effect on the SAR value. It should be noted that the brain-averaged SAR for a 10-week-old rat was same for all three cases, because the digital models were normalized on a 10-week-old rat; i.e., for the size-only change, the permittivity values of a 10-week-old rat were used for all the four ages, whereas for permittivity variation, only the size of a 10-week-old rat was used for all the four ages.

3-1 SAR Variation on Size Changes

The SAR values were computed using the FDTD simulation for four different sizes using the tissue permittivities of a 10-week SD rat to examine the sensitivity of its brain SAR with regard to size only variation. Fig. 3 shows a cross-section view of the SAR distribution inside the brain of a 10-week-old rat. The one-voxel peak SAR and the brain-averaged SAR were obtained from the SAR value distribution inside the brain.



(a) Dielectric constant



(b) Conductivity

Fig. 2. Data-fitting of Gabriel's data at 1,800 MHz.

Table 4 shows the 1-voxel peak SAR of the brain and the brain-averaged SAR of the four different sizes at 900 MHz and 1800 MHz. It is shown that the brain-

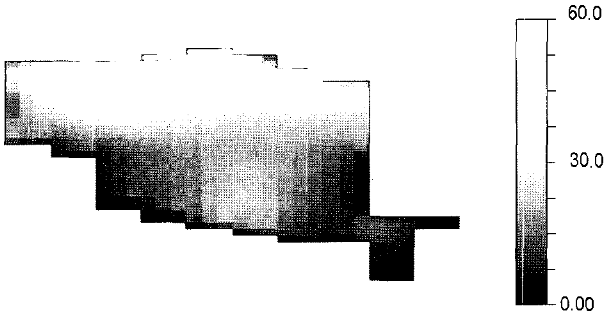


Fig. 3. SAR distribution inside the brain of a 10 week-old rat.

Table 4. SAR variation on size change of SD rat.

Age (week)	SAR (W/kg/Win)			
	900 MHz		1,800 MHz	
	1 Voxel Peak	Brain Avg.	1 Voxel Peak	Brain Avg.
3	82.7	28.8	67.3	32.9
4	65.7	25.0	45.8	21.0
7	60.1	19.5	36.2	11.8
10	61.0	18.7	30.2	10.3

averaged SAR decreases as the size of the SD rat increases. At 900 MHz, the brain-averaged SAR of a 3-week-old rat was about 54 % higher than a 10-week-old rat at 900 MHz, and about 3.19 times at 1,800 MHz, which is similar to the trend shown in [4]. The one voxel peak SAR also showed a trend that decreases as the size increases, because the thicknesses of the skin and skull as well as the size of brain of a young rat was relatively smaller than that of an adult rat.

3-2 SAR Variation on Permittivity Changes

We tried to examine the effect of the change in tissue permittivity(dielectric constant and conductivity) on the SAR values while keeping the size constant, e.g., size of a 10-week-old SD rat at this time. Table 5 shows the one-voxel peak SAR and the brain-averaged SAR of five different permittivity arrangements. The brain-averaged SAR was higher for younger rats. Especially in this case, we considered a 2 week-old rat. The brain-averaged SAR of a 2-week-old rat was about 21 % higher than a 10-week-old rat at 900 MHz, and 18 % higher at 1,800 MHz.

The result of the SAR vatiation on permittivity changes also shows younger rat has lower SAR values. The result also shows that the sensitivity of the brain-averaged SAR on permittivity was much lower than that on size, because the increasing rate of the SAR values for the permittivity only change is much smaller than that for the size-only change.

Table 5. SAR variation on permittivity changes.

Age (week)	SAR (W/kg/Win)			
	900 MHz		1,800 MHz	
	1 Voxel Peak	Brain Avg.	1 Voxel Peak	Brain Avg.
2	61.8	22.7	36.4	12.2
3	60.1	21.6	36.0	11.3
4	60.1	20.3	36.0	11.2
7	58.0	19.1	30.5	10.2
10	61.6	18.7	30.2	10.3

The one-voxel peak SAR does not show any substantial difference among the five different permittivity arrangements, because the peak SAR occurs near the boundary of the skull so it is more affected by size values than pemittivity.

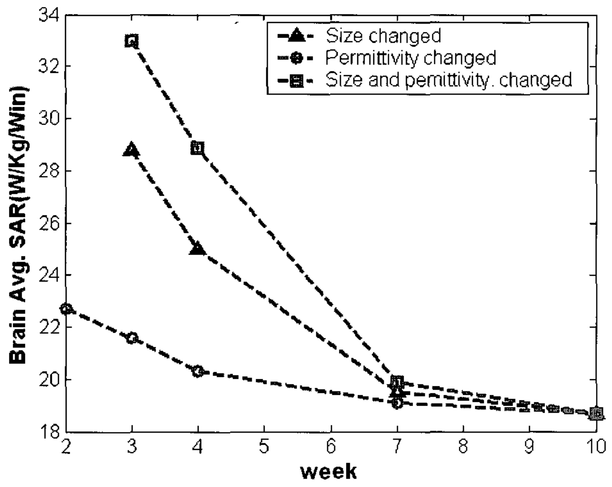
3-3 SAR Variation on Changes in Both Size and Permittivity

The sensitivity of the brain-averaged SAR on changes in both size and permittivity were examined with four different SD rat models as shown in Table 6. The brain-averaged SAR decreased as the rat's age increased, which was expected from the previous results. In addition, the decreasing rate was slightly higher than that in the case of a size-only change. The brain- averaged SAR of a 3-week-old rat was about 77 % higher than that of a 10-week-old rat at 900 MHz, and was 207 % higher at 1,800 MHz.

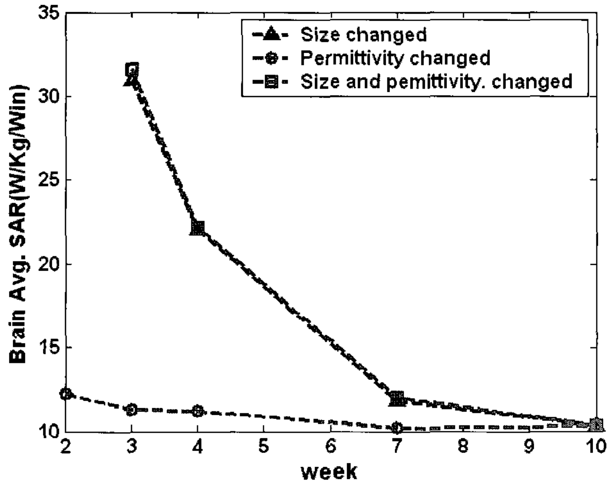
Fig. 4 (a) and (b) show the summary of the numerical computation results shown in Tables 4~6 for the brain-averaged SAR.

Table 6. SAR variation on changes in both size and permittivity.

Age (week)	SAR (W/kg/Win)			
	900 MHz		1,800 MHz	
	1 Voxel Peak	Brain Avg.	1 Voxel Peak	Brain Avg.
3	78.0	33.1	71.0	32.6
4	73.3	28.9	55.3	21.4
7	60.6	19.9	36.1	12.0
10	61.6	18.7	30.2	10.3



(a) at 900 MHz



(b) at 1,800 MHz

Fig. 4. Brain-averaged SAR variations in 3 cases.

Ⅳ. Conclusion

In this paper, the SAR variations of a rat's brain which correspond to the size and/or permittivity values of four different ages (3-, 4-, 7- and 10-week-old rats) at the frequency band of a commercial mobile phone (900 MHz and 1,800 MHz) using the FDTD technique with PML absorbing boundaries were examined. First, the preciseness of the FDTD code was verified with other commercial tools for a simple structure. Then the electric fields inside of the color-coded digital rat model were computed with the FDTD code, and consequently, the SAR value for each voxel and the brain-averaged SAR value were computed. Finally, the sensitivity of the brain-averaged SAR on changes in size and/or permittivity values was examined using the numerical results which were obtained from four different digital models corresponding to different ages.

At 900 MHz, the simulation results show that the brain-averaged SAR values decreased by about 54 % for rat size variation from the 3-week to the 10-week-old rat model, while the SAR values decreased by only about 21 % fin terms of permittivity variation. The sensitivity of the brain-averaged SAR on permittivity is much lower than that on size. It was found that the brain-averaged SAR values decreased by about 77 % if there were a change in both the size and permittivity. At 1,800 MHz, the brain-averaged SAR value decreased by 200 % for size variation, 18.4 % for permittivity variation, and 207 % for both size and permittivity variations.

Acknowledgment

We would like to thank Ae-Kyoung Lee of Electronic Telecommunication Research Institute(ETRI) for providing the color-coded digital images. We would also like to thank Jong-Kwan Yook(Yonsei University), Jung-Ki Pack(Chungnam National University), Gye-Jae Lim(Kwandong University) and Hyun-Bo Yoon(Dongguk University) for their help.

References

[1] http://www.iegmp.org.uk/report/summary.htm

[2] P. A. Mason, W. D. Hurt, T. J. Walters, J. A. D'andrea, P. G. Gajsek, K. L. Ryan, D. A. Nelson, K. I. Smith, and J. M. Ziriax, "Effects of frequency, permittivity, and voxel size on predicted specific absorption rate values in biological tissue during electromagnetic-field exposure", *IEEE Trans. on MTT*, vol. 48, no. 11, 2000.

[3] C. K. Chou, K. W. Chan, J. A. McDougall, and A. W. Guy, "Development of rat head exposure system for simulating human exposure to RF fields from handheld wireless telephones", *Bioelectromagnetics*, vol. 20, no. S4, pp. 64-74, 1999.

[4] F. Schonborn, K. Pokovic, and N. Kuster, "Dosimetric analysis of the carousel setup for the exposure of rats at 1.62 GHz", *Bioelectromagnetics*, vol. 25, no. 1, pp. 16-26, 2004.

[5] S. P. Mathur, S. T. Lu, "Application of various thermometric calorimetry in rodent dosimetry", *Proc. Biological Effects of Electromagnetic Fields 2nd Workshop*, 2002.

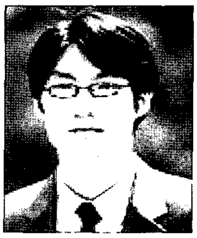
[6] A. Peyman, A. A. Rezazadeh, and C. Gabriel, "Changes in the dielectric properties of rat tissue as a function of age at microwave frequencies", *Phys. Med. Biol.*, vol. 46, pp. 1617-1629, 2001.

[7] P. A. Mason, T. J. Walters, J. W. Fanton, D. N. Erwin, J. H. Gao, J. W. Roby, J. L. Kane, K. A. Lott,

E. Lott, and R. V. Blystone, "Database created from magnetic resonance images of a Spague-Dawley rat, rhesus monkey, and pigmy goat", *the FASEB Journal*, vol. 9, pp. 434-440, 1995.

[8] http://www.fcc.gov/cgi-bin/dielec.sh

Jong-Chul Hyun



He received the B.S. and M.S. degrees in radio science and communication engineering from Hongik University, Seoul, Korea, in 2004 and 2006, respectively. His current research interests include wave scattering, antennas, and EMI/EMC.

Yisok Oh

He received the B.S. degree in electrical engineering from Yonsei University, Seoul, Korea, in 1982, the M.S. degree in Electrical Engineering from the University of Missouri-Rolla, in 1988 and the Ph.D. degree in electrical engineering from the University of Michigan, Ann Arbor, in 1993. He is currently an associate professor at Hongik University, Seoul, Korea. His current research interests include microwave scattering from earth surfaces, antennas and radio wave propagation.