Proceedings of the 6th WSEAS International Conference on Applied Informatics and Communications, Elounda, Greece, August 18-20, 2006 (pp323-327)

A Combined Computational and Experimental Investigation of Nonthermal Biological Effects on Prenatal Development due to Radiation from Low Power Microwave Antennas

T. V. YIOULTSIS[1], T. I. KOSMANIS[1], T. T. ZYGIRIDIS[1], E. P. KOSMIDOU[1], A. PYRPASOPOULOU[3], T. D. XENOS[1], N. J. FARSARIS[1], V. KOTOULA[3], P. M. HYTIROGLOU[3], G. KARKAVELAS[3], I. N. MAGRAS[2] AND T. D. TSIBOUKIS[1]

[1]Dept. of Electrical and Computer Engineering, Div. of Telecommunications

[2]School of Veterinary Medicine, Anatomy, Histology and Embryology Lab

[3]School of Medicine, Lab. of Pathology

Aristotle University of Thessaloniki, GR-54006, Thessaloniki, Greece

Abstract – This is an integrated study of the biological effects of pulse-modulated very low power density microwave radiation. It employs a combination of a computational model of the rat and extensive *in vivo* experiments on rat embryos, during embryogenesis and organogenesis. The whole investigation is further enhanced via an immunological and chemical investigation of the rats' organs. The whole study is one of the first to combine results obtained by the computational, the experimental and the biomolecular investigations and attempts a discussion on existing standards for protection from low power density, long-term electromagnetic field exposure.

Keywords: Nonthermal Effects, Non-Ionizing Radiation, Electromagnetic Compatibility, FDTD.

1.Introduction

One of the most important areas of research in bioelectromagnetics, is the investigation of the effects of radiation, especially in extremely sensitive biological processes, such as the prenatal development. The majority of computational investigations deal with high power densities and short times of exposure, such as the studies of interaction of mobile phones with models of the human head [1-2]. On the other hand, experimental investigations were mainly carried out with birds and small experimental mammals, usually rodents, for high power densities [3-4]. These studies deal with thermal effects ending to congenital malformations, embryonic and foetal deaths. Investigations of nonthermal effects also exist [5-6], although their occurrence is not yet statistically evaluated. However, the wide use of RF spectrum in personal communications, raise the issue of possible effects of low power radiation, under chronic exposure terms. Typical cases that have not been yet widely considered are those of a Wireless Local Area Network (WLAN) system, of antenna parks and of ground based radars that are in close proximity to urban areas.

This study is a result of a coordinated scientific research among three groups, attempting an integrated approach the issue of nonthermal effects of microwave irradiation. It focuses on the investigation of very low power radiation on the prenatal development of rats. The choice of rats as experimental animals is justified by the fact that the first very critical steps of prenatal development have a close resemblance to those of human embryos. The computational model is based on an FDTD approach [7], which results in an accurate estimation of the electric field and the specific absorption rate (SAR) in rat tissues, under specified conditions of irradiation.

However, apart from the computational results, which provide a rough prediction of the exposure conditions, more definite conclusions are derived by means of an experimental approach, based on the exposure of pregnant rats to microwave radiation and the macro- and microscopical examination of the newborns. Although no significant deviations in weight and length have been observed, a high percentage of pregnant rats that did not give birth at all and their uteri presented significant alterations. The results are further supported by evidence from the histochemical examination, the investigation by electronic microscope and molecular pathology techniques [8], substantiating the fact that very low power density microwaves, below the limits imposed by safety standards [9-10], can cause adverse biological effects.

2. The computational FDTD

A detailed three-dimensional computational model of the rat had to be developed by the authors, since such studies and models do not yet exist, while models of the human head are widely available. The construction of the solid computer model has been enabled, due to the use of a detailed set of anatomical images, enhanced by precise and comprehensive inspection of the rat's internal structure, during the anatomic process. At the frequencies considered in this study, a very fine mesh is required, which is further enhanced by an appropriate subgridding technique, to model the very thin structure of the uterus at the first stages of pregnancy.

The excitation used in the FDTD calculations has the general form of a modulated pulse,

$$E_i = E_0 \sum_n (1 - e^{-\frac{t-nT}{T_0}}) \sin(2\pi f t)[u(t-nT) - u(t-nT-\tau)], \quad (1)$$

Where, a suitable exponential term is added in the simulation to reduce numerical dispersion. The electric field amplitude is chosen according to the experimental setup to relate the observed effects to electric field or SAR levels, either local or averaged. The results obtained from the FDTD analysis are, thus, necessary to provide sufficient basis for discussion on whether the existing standards of long-term exposure are trustworthy.

3. The experimental study

The microwave setup consists of an X-band microwave generator with a maximum power output of +25dBm, a 27cm horn-fed parabolic reflector antenna with a 26dB gain at 9.152 GHz and an X-band waveguide network connecting the generator to the antenna. A –20 dB directional coupler has been used to continuously monitor the microwave signal. Of great importance is the choice of frequency, based on the overall body resonance and the relation of the skin depth compared to rat's size. This treatment is a prerequisite for any attempt to project the results to humans, at UHF, L- or S- bands.

The rat cages were placed 5m away from the antenna, to ensure far field irradiation conditions and at the maximum of its main lobe. A microwave power density of 5 $\mu W/cm^2$ at 9.35 GHz was chosen, monitored by a spectrum analyzer, via a standard gain (16 dB) horn antenna, whereas the characteristics of connecting cables were measured by a network analyzer. The electromagnetic power densities, applied and background, were cross - checked by a power meter (PMM 8053) and a reference probe (EP 330). All measurements were performed according to the relevant IEEE standard [11].

For the experiments, groups of pregnant rats[1] have been exposed to microwave radiation during the first days of pregnancy. In particular, the rats were irradiated during the stages of embryogenesis (from the first to the third day after fertilization) and organogenesis (which takes place from the fourth to ninth day). After delivery, the newly born rats were sacrificed by euthanasia and precisely examined for any possible malformations. Since low or total infertility was observed to a great extent, all mothers were also sacrificed by euthanasia and their uteri were examined for any possible indications of dead embryos or foetuses.

Finally, the organs of all animals were disected and processed using histological, immunohistological and molecular techniques to detect possible alteration at the histological and molecular level.

4. Computational and experimental results

Several cases of exposure have been considered and the most adverse conditions of irradiation have been studied. The radiation is assumed incident on rat's back.

Some characteristic graphs of local SAR values, in logarithmic (dB) scale, with respect to 1 W/Kg, are shown in Fig. 1. The average SAR, maximum SAR and maximum 1g average SAR values are shown in Table I. Inspection of Fig. 1 shows that the local SAR values are of the same order of magnitude in both cases. All values are extremely low, compared to those of common standards [10] therefore no considerable thermal effects can be produced.

However, the experimental investigation showed a considerable effect on fertility. In particular, three experiments were simultaneously conducted and the pregnant rats were grouped accordingly. The first experiment has been conducted using 20 pregnant rats, exposed during the organogenesis for six hours per day, except for one group, which has been continuously exposed (Table II). The second one involved 19 rats, exposed for different times during embryogenesis (Table III). In the third experiment, 13 female rats were used and the conditions were similar

[1] The use of this experimental material was approved by the Veterinary service of the Municipality of Thessaloniki according to the provisions of the laws 1197/81 and 2015/92 and the Presidental Decree 160/91 of the Greek Democracy.

to those of the second one (Table IV). Finally a group of 10 rats was not exposed and have been used as controls

In all cases, the weight and length of the newborns did not present any statistically significant differentiation and no abnormality has been observed in skeletal development. However, low or total infertility was observed to a great extent and the uteri of rats that did not give birth, were examined for indications of dead embryos or foetuses (Table V). In many cases, endometritis (E) was found, which indicates that embryos have been absorbed before the implantation, due to the fact that they were not viable. In other cases, the uteri had tips (T) on their walls, which is a sign of absorbed dead embryos at the beginning of implantation. To a small extent, nodules (N) were found, implying death after implantation and before the morphogenesis. The occurrence of such phenomena seems to be related to the duration of exposure and the stage of pregnancy, when the irradiation took place.

Moreover, no major differences were observed macroscopically or at the histological level between non-irradiated animals and newborns, which were exposed to radiation during fetal life. However, hydropic changes were observed occasionally in the second group to a varying extent in the liver and kidneys.

At the molecular level, BMP4, a growth factor which belongs to the bone morphogenetic protein-family of growth factors, was specifically induced in distinct cell types of the kidney and lung (Fig. 5); the level of induction was related to the duration of exposure during pregnancy. Expression of BMP receptors (especially R-IA) was also upregulated. Due to the significance of BMP4 in the development of kidney, lung and a variety of organs, further investigation of the observed aberrant gene expression seems mandatory [12].

5. Conclusions

The nonthermal effects of low power microwaves, are thoroughly investigated in this study. The computational analysis, provides an essential tool to predict the values of power density and SAR for experimental cases, which could be associated with harmful influences of radiation, while the macroscopical, histological and molecular investigation reveals the effects of low power microwave radiation to rat embryos. Although it is difficult to project the results in the case of human beings, the possibility of adverse effects of a prolonged exposure in very low power microwaves cannot be ruled out and should be further investigated. The study is ongoing, including more experiments for a firm statistical evaluation. This forms an entirely new basis for discussion on existing safety levels and their improvement.

Acknowledgement

This work was supported by the Greek General Secretariat of Research and Technology (Grant No. ED325/PENED 99).

References

[1] P. Bernardi, M. Cavagnaro, S. Pisa and E. Piuzzi, “Specific Absorption Rate and Temperature Increases in the Head of a Cellular-Phone User,” *IEEE Trans. Microw. Theory Tech.*, vol. 48, pp. 1118-1126, Jul. 2000.

[2] G. Lazzi, S. S. Pattnaik, C. M. Furse and O. P. Gandhi, “Comparison of FDTD Computed and Measured Radiation Patterns of Commercial Mobile Telephones in Presence of the Human Head,” *IEEE Trans. Antennas Propag.*, vol. 46, pp. 943-944, 1998.

[3] R. Jensh, et al., "Teratogenic effects on rat offspring of non-thermal chronic prenatal microwave irradiation", *Teratol.*, vol. 17, no. 2, 1978.

[4] J. M. Larry and D. L. Connover, “Teratogenic effects of radiofrequency radiation,” *IEEE Eng. Medicine and Biology*, pp 42-46, 1987.

[5] J. Tanner and C. Romero-Sierra, "The effects of chronic exposure to very low intensity microwave radiation on domestic fowl,” *J. Bioelectr.*, vol. 1, no. 2, pp 195-205, 1982.

[6] D. McRee and R. Hamrick, "Exposure of Japanese quail embryos to 2.45 GHz microwave radiation during development," *Radiation Res.*, vol. 71, pp. 355-366, 1997.

[7] A. Taflove, ed., *Advances in Computational Electrodynamics: The Finite-Difference Time-Domain Method*. Boston: Artech House, 1998.

[8] Bodamyali et al. "Pulsed electromagnetic fields simulataneously induce ostegenesis and upregulate transcription of bone morphogenetic proteins 2 and 4 in rat osteoblasts in vitro," *Biochem. Biophys. Res. Commun.*, vol. 18, no. 250, pp. 458-461, 1998.

[9] P. Czerski, “Radio frequency radiation exposure limits in Eastern Europe”. *J. Microw. Power*, vol. 21, no. 1, pp. 9-23,1986.

[10] *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields*. IEEE C95.1, IEEE New York, 1995.

[11] *IEEE recommended practice for the measurement of potentially hazardous electromagnetic fields – RF and microwaves*. IEEE C95.3, IEEE New York, 1991.

[12] Pyrpasopoulou A, Kotoula V., Cheva A, Nikolakaki E, Hytiroglou P, Magras I, Xenos Th, Tsiboukis Th, Karkavelas G, "Bone morphogenic protein expression in newborn rat kidneys after prenatal exposure to radiofrequency radiation", *Bioelectromagnetics*, vol. 25, pp. 216-227, 2004

Figures and tables

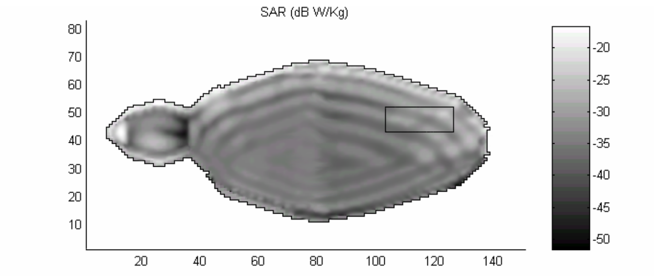
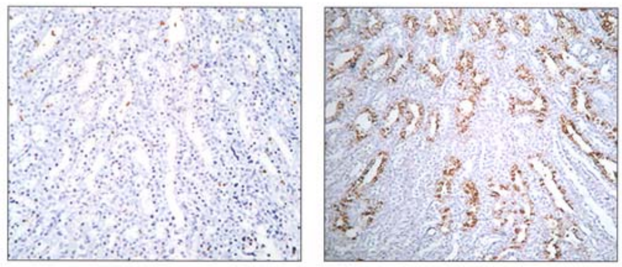


Fig. 1. SAR image, in dB scale with respect to 1 W/Kg, in a vertical section of the rat. The rectangle indicates the uterus area.



(a) (b)

Fig. 2. Comparison of BMP4 factor for kidney cells (a) controls (b) exposed to radiation.

TABLE I. COMPARISON OF SAR VALUES

	Power density (μW/cm^2)	Average SAR (mW/Kg)	Maximum SAR (mW/Kg)	Max 1g Avg SAR (mW/Kg)
Pregnant Rat	5.000	1.024	18.599	2.223

TABLE II. FIRST EXPERIMENT

Groups	I	II	III	IV	V
Exposure (days)	4	4	4	4	4
Hours per day	6	6	6	6	24
Gave birth	1/4	1/4	1/4	1/4	2/4
Newborns	5	11	11	5	8, 6
E	-	-	-	-	-
T	-	2/3	1/3	1/3	1/2
N	-	-	-	-	-

TABLE III. SECOND EXPERIMENT

Groups	A	D	K
Exposure time (hours)	24	48	72
Gave birth	1/5	2/5	2/5
Newborns	7	9, 12	11, 8
E	1/4	3/3	1/3
T	1/4	-	-
N	1/4	-	-

TABLE IV. THIRD EXPERIMENT

Groups	I	II	III
Exposure time (hours)	24	48	72
Gave birth	1/3	1/3	1/4
Born	10	12	10
E	1/2	-	-
T	-	-	-
N	-	-	-

TABLE V. CONTROLS

Groups	M
Exposure time (hours)	-
Gave birth	8/10
Born	4, 11, 12, 11, 11, 10, 12, 10
E	-
T	-
N	-

E: possible early deaths before implantation, T: possible early deaths at the beginning of the implantation, N: possible early deaths before morphogenesis