

4/6/03

Studies reporting biological effects of radiofrequency radiation (RFR) at low intensities

1. Balode (1996)- blood cells from cows from a farm close and in front of a radar showed significantly higher level of severe genetic damage.

2. Boscol et al. (2001)- RFR from radio transmission stations (0.005 mW/cm²) affects immunological system in women.

3. Chiang et al. (1989)- people lived and worked near radio antennae and radar installations showed deficits in psychological and short-term memory tests.

(4) de Pomerai et al. (2000, 2002) reported an increase in a molecular stress response in cells after exposure to a RFR at a SAR of 0.001 W/kg. This stress response is a basic biological process that is present in almost all animals - including humans.

1. de Pomerai et al. (2003) RFR damages proteins at 0.015-0.020 W/kg.

(6) D'Inzeo et al. (1988)- very low intensity RFR (0.002 – 0.004 mW/cm²) affects the operation of acetylcholine-related ion-channels in cells. These channels play important roles in physiological and behavioral functions.

(7) Dolk et al. (1997)- a significant increase in adult leukemias was found in residence who lived near the Sutton Coldfield television (TV) and frequency modulation (FM) radio transmitter in England.

(8) Dutta et al. (1989) reported an increase in calcium efflux in cells after exposure to RFR at 0.005 W/kg. Calcium is an important component of normal cellular functions.

(9) Fesenko et al. (1999) reported a change in immunological functions in mice after exposure to RFR at a power density of 0.001 mW/cm².

(10) Hjollund et al. (1997)- sperm counts of Danish military personnel, who operated mobile ground-to-air missile units that use several RFR emitting radar systems (maximal mean exposure 0.01 mW/cm²), were significantly low compared to references.

(11) Hocking et al. (1996)- an association was found between increased childhood leukemia incidence and mortality and proximity to TV towers.

(12) Ivaschuk et al. (1999)- short-term exposure to cellular phone RFR of very low SAR (26 mW/kg) affected a gene related to cancer.

(13) Kolodynski and Kolodynska (1996)- school Children lived in front of a radio station had less developed memory and attention, their reaction time was slower, and their neuromuscular apparatus endurance was decreased.

(14) Kwee et al. (2001)- 20 minutes of cell phone RFR exposure at 0.0021 W/kg increased stress protein in human cells.

(15) Lebedeva et al. (2000)- brain wave activation was observed in human subjects exposed to cellular phone RFR at 0.06 mW/cm².

(16) Magras and Xenos (1999) reported a decrease in reproductive function in mice exposed to RFR at power densities of 0.000168 - 0.001053 mW/cm².

(17) Mann et al. (1998)- a transient increase in blood cortisol was observed in human subjects exposed to cellular phone RFR at 0.02 mW/cm². Cortisol is a hormone involved in stress reaction.

(18) Michelozzi et al. (1998)- leukemia mortality within 3.5 km (5,863 inhabitants) near a high power radio-transmitter in a peripheral area of Rome was higher than expected.

(19) Michelozzi et al. (2002)- childhood leukemia higher at a distance up to 6 km from a radio station.

(20) Navakatikian and Tomashevskaya (1994)- RFR at low intensities (0.01 - 0.1 mW/cm²; 0.0027- 0.027 W/kg) induced behavioral and endocrine changes in rats. Decreases in blood concentrations of testosterone and insulin were reported.

(21) Novoselova et al. (1999)-low intensity RFR (0.001 mW/cm²) affects functions of the immune system.

(22) Persson et al. (1997) reported an increase in the permeability of the blood-brain barrier in mice exposed to RFR at 0.0004 - 0.008 W/kg. The blood-brain barrier envelops the brain and protects it from toxic substances.

(23) Phillips et al. (1998) reported DNA damage in cells exposed to RFR at SAR of 0.0024 - 0.024 W/kg.

(24) Polonga-Moraru et al. (2002) change in membrane of cells in the retina (eye) after exposure to RFR at 15 W/cm².

(25) Salford et al. (2003)- nerve cell damage in brain of rats exposed for 2 hrs to GSM signal at 0.02 W/kg.

(26) Santini et al. (2002)- increase in complaint frequencies for tiredness, headache, sleep disturbance, discomfort, irritability, depression, loss of memory, dizziness, libido decrease, in people who lived within 300 m of mobile phone base stations.

(27) Schwartz et al. (1990)- calcium movement in the heart affected by RFR at SAR of 0.00015 W/kg. Calcium is important in muscle contraction. Changes in calcium can affect heart functions.

(28) Somosy et al. (1991)- RFR at 0.024 W/kg caused molecular and structural changes in cells of mouse embryos.

(29) Stagg et al. (1997)- glioma cells exposed to cellular phone RFR at 0.0059 W/kg showed significant increases in thymidine incorporation, which may be an indication of an increase in cell division.

(30) Stark et al. (1997)- a two- to seven-fold increase of salivary melatonin concentration was observed in dairy cattle exposed to RFR from a radio transmitter antenna.

(31) Tattersall et al. (2001)- low-intensity RFR (0.0016 - 0.0044 W/kg) can modulate the function of a part of the brain called the hippocampus, in the absence of gross thermal effects. The changes in excitability may be consistent with reported behavioral effects of RFR, since the hippocampus is involved in learning and memory.

(32) Vangelova et al. (2002)- operators of satellite station exposed to low dose (0.1127 J/kg) of RFR over a 24-hr shift showed an increased excretion of stress hormones.

(33) Velizarov et al. (1999) showed a decrease in cell proliferation (division) after exposure to RFR of 0.000021 - 0.0021 W/kg.

(34) Veyret et al. (1991)- low intensity RFR at SAR of 0.015 W/kg affects functions of the immune system.

(35) Wolke et al. (1996)- RFR at 0.001W/kg affects calcium concentration in heart muscle cells of guinea pigs.

Source of literature and abstracts:

(1) Balode, Z, Assessment of radio-frequency electromagnetic radiation by the micronucleus test in bovine peripheral erythrocytes. *Sci Total Environ* 180(1):81-85, 1996.

Previous bioindicative studies in the Skrunda Radio Location Station area have focused on the somatic influence of electromagnetic radiation on plants, but it is also important to study genetic effects. We have chosen cows as test animals for cytogenetical evaluation because they live in the same general exposure area as humans, are confined to specific locations and are chronically exposed to radiation. Blood samples were obtained from female Latvian Brown cows from a farm close to and in front of the Skrunda Radar and from cows in a control area. A simplified alternative to the Schiff method of DNA staining for identification of micronuclei in peripheral erythrocytes was applied. Microscopically, micronuclei in peripheral blood erythrocytes were round in shape and exhibited a strong red colour. They are easily detectable as the only coloured bodies in the uncoloured erythrocytes. From each individual animal 2000 erythrocytes were examined at a magnification of x 1000 for the presence of micronuclei. The counting of micronuclei in peripheral erythrocytes gave low average incidences, 0.6 per 1000 in the exposed group and 0.1 per 1000 in the control, but statistically significant ($P < 0.01$) differences were found in the frequency distribution between the control and exposed groups.

(2) Boscol P, Di Sciascio MB, D'Ostilio S, Del Signore A, Reale M, Conti P, Bavazzano P, Paganelli R, Di Gioacchino M. Effects of electromagnetic fields produced by radiotelevision broadcasting stations on the immune system of women. *Sci Total Environ* 273(1-3):1-10, 2001. The object of this study was to investigate the immune system of 19 women with a mean age of 35 years, for at least 2 years (mean = 13 years) exposed to electromagnetic fields (ELMFs) induced by radiotelevision broadcasting stations in their residential area. In September 1999, the ELMFs (with range 500 KHz-3 GHz) in the balconies of the homes of the women were (mean +/- S.D.) 4.3 +/- 1.4 V/m. Forty-seven women of similar age, smoking habits and atopy composed the control group, with a nearby resident ELMF exposure of < 1.8 V/m. Blood lead and urinary trans-trans muconic acid (a metabolite of benzene), markers of exposure to urban traffic, were higher in the control women. The ELMF exposed group showed a statistically significant reduction of blood NK CD16+ - CD56+, cytotoxic CD3(-) - CD8+, B and NK activated CD3(-) - HLA-DR+ and CD3(-) - CD25+ lymphocytes. 'In vitro' production of IL-2 and interferon-gamma (INF-gamma) by peripheral blood mononuclear cells (PBMC) of the ELMF exposed group, incubated either with or without phytohaemoagglutinin (PHA), was significantly lower; the 'in vitro' production of IL-2 was significantly correlated with blood CD16+ - CD56+ lymphocytes. The stimulation index (S.I.) of blastogenesis (ratio between cell proliferation with and without PHA) of PBMC of ELMF exposed women was lower than that of the control subjects. The S.I. of blastogenesis of the ELMF exposed group (but not blood NK lymphocytes and the 'in vitro' production of IL-2 and INF-gamma by PBMC) was significantly correlated with the ELMF levels. Blood lead and urinary trans-trans muconic acid

were barely correlated with immune parameters: the urinary metabolite of benzene of the control group was only correlated with CD16⁺-CD56⁺ cells indicating a slight effect of traffic on the immune system. In conclusion, this study demonstrates that high frequency ELMFs reduce cytotoxic activity in the peripheral blood of women without a dose-response effect.

(3) Chiang H, Yao GD, Fang QS, Wang KQ, Lu DZ, Zhou YK, Health effects of environmental electromagnetic fields. *J. Bioelectricity* 8:127-131, 1989.

We investigated the effects of exposure to environmental electromagnetic fields (EMFs) in 1170 subjects. Neutrophil phagocytosis was enhanced in the low-intensity exposure groups, but reduced significantly at relatively higher intensities. Visual reaction time was prolonged and the scores of short-term memory tests were lower in some high-intensity exposure groups. EMFs may affect the central nervous and immune systems in man.

(4) de Pomerai D, Daniells C, David H, Allan J, Duce I, Mutwakil M, Thomas D, Sewell P, Tattersall J, Jones D, Candido P, Non-thermal heat-shock response to microwaves, *Nature* 405:417-418, 2000.

Nematode worms (*C. elegans*) exposed overnight to 750-MHz microwaves at a SAR of 0.001 W/kg showed an increased in heat shock proteins (HSPs). (Heat shock proteins are induced in most organisms by adverse conditions (such as heat or toxins) that cause damage to cellular proteins, acting as molecular chaperones to rescue damaged proteins). The authors give several arguments that the microwave-induced effect on HSPs is non-thermal and suggest that 'current exposure limits for microwave equipment may need to be reconsidered.'

de Pomerai DI, Dawe A, Djerbib L, Allan, Brunt G, Daniells C. Growth and maturation of the nematode *Caenorhabditis elegans* following exposure to weak microwave fields. *Enzyme Microbial Tech* 30:73-79, 2002.

Prolonged exposure to weak microwave fields (750-1000 MHz, 0.5 W) at 25°C induces a heat-shock response in transgenic *C. elegans* strains carrying *hsp16* reporter genes [1]. A comparable response to heat alone requires a substantially higher temperature of 28°C, suggesting that microwave heating of worms or of the system as a whole might provide a sufficient explanation, although this can be ruled out by indirect arguments [1]. Here we investigate two further biological consequences of prolonged microwave exposure at 25°C in synchronised cultures of wild-type worm larvae, namely alterations in (i) growth rate (GR) and (ii) the proportion of worms later maturing into egg-bearing adults (MP). Both of these parameters are significantly increased following microwave exposure (GR by 8-11%, and MP by 28-40%), whereas both are significantly decreased (GR by 10% and MP almost abolished) after mild heat treatment at 28°C for the same period. It follows that the biological consequences of microwave exposure are opposite to, and therefore incompatible with, those attributable to mild heating. This evidence does not in itself necessitate a non-thermal mechanism, but does

eliminate explanations that invoke the bulk heating of tissues by microwaves. This latter, however, remains the sole basis for current regulations governing microwave exposure.

(5) de Pomerai DI, Smith B, Dawe A, North K, Smith T, Archer DB, Duce IR, Jones D, Candido EP. Microwave radiation can alter protein conformation without bulk heating. *FEBS Lett* 22;543(1-3):93-97, 2003. Exposure to microwave radiation enhances the aggregation of bovine serum albumin in vitro in a time- and temperature-dependent manner. Microwave radiation also promotes amyloid fibril formation by bovine insulin at 60 degrees C. These alterations in protein conformation are not accompanied by measurable temperature changes, consistent with estimates from field modelling of the specific absorbed radiation (15-20 mW kg(-1)). Limited denaturation of cellular proteins could explain our previous observation that modest heat-shock responses are induced by microwave exposure in *Caenorhabditis elegans*. We also show that heat-shock responses both to heat and microwaves are suppressed after RNA interference ablating heat-shock factor function.

(6) D'Inzeo G, Bernardi P, Eusebi F, Grassi F, Tamburello C, Zani BM, Microwave effects on acetylcholine-induced channels in cultured chick myotubes. *Bioelectromagnetics* 9(4):363-372, 1988. The behavior of cultured myotubes from chick embryos exposed to microwaves has been experimentally analyzed. Recordings of acetylcholine-induced currents have been obtained via patch-clamp techniques using both cell-attached (single-channel current recording) and whole-cell (total current recording) configurations. During the exposure to low-power microwaves the frequency of the ACh-activated single channel openings decreased, while the ACh-induced total current showed a faster falling phase. Channel open time and conductance were not affected by microwave irradiation. It is concluded that the exposure to microwaves increases the rate of desensitization and decreases the channel opening probability. The nonthermal origin and the molecular interaction mechanisms governing these electromagnetic-induced effects are discussed.

(7) Dolk H, Shaddick G, Walls P, Grundy C, Thakrar B, Kleinschmidt I, Elliott P, Cancer incidence near radio and television transmitters in Great Britain. I. Sutton Coldfield transmitter. *Am J Epidemiol* 145(1):1-9, 1997.

A small area study of cancer incidence in 1974-1986 was carried out to investigate an unconfirmed report of a "cluster" of leukemias and lymphomas near the Sutton Coldfield television (TV) and frequency modulation (FM) radio transmitter in the West Midlands, England. The study used a national database of postcoded cancer registrations, and population and socioeconomic data from the 1981 census. Selected cancers were hematopoietic and lymphatic, brain, skin, eye, male breast, female breast, lung, colorectal, stomach, prostate, and bladder. Expected numbers of cancers in small areas were calculated by indirect standardization, with stratification for a small area socioeconomic index. The study area was defined as a 10 km radius circle around the transmitter, within which 10 bands of increasing distance from the transmitter were defined as a basis for testing for a decline in risk with distance, and an inner area was

arbitrarily defined for descriptive purposes as a 2 km radius circle. The risk of adult leukemia within 2 km was 1.83 (95% confidence interval 1.22-2.74), and there was a significant decline in risk with distance from the transmitter ($p = 0.001$). These findings appeared to be consistent over the periods 1974-1980, 1981-1986, and were probably largely independent of the initially reported cluster, which appeared to concern mainly a later period. In the context of variability of leukemia risk across census wards in the West Midlands as a whole, the Sutton Coldfield findings were unusual. A significant decline in risk with distance was also found for skin cancer, possibly related to residual socioeconomic confounding, and for bladder cancer. Study of other radio and TV transmitters in Great Britain is required to put the present results in wider context. No causal implications can be made from a single cluster investigation of this kind.

(8) Dutta SK, Ghosh B, Blackman CF, Radiofrequency radiation-induced calcium ion efflux enhancement from human and other neuroblastoma cells in culture. *Bioelectromagnetics* 1989;10(2):197-202 To test the generality of radiofrequency radiation-induced changes in $^{45}\text{Ca}^{2+}$ efflux from avian and feline brain tissues, human neuroblastoma cells were exposed to electromagnetic radiation at 147 MHz, amplitude-modulated (AM) at 16 Hz, at specific absorption rates (SAR) of 0.1, 0.05, 0.01, 0.005, 0.001, and 0.0005 W/kg. Significant $^{45}\text{Ca}^{2+}$ efflux was obtained at SAR values of 0.05 and 0.005 W/kg. Enhanced efflux at 0.05 W/kg peaked at the 13-16 Hz and at the 57.5-60 Hz modulation ranges. A Chinese hamster-mouse hybrid neuroblastoma was also shown to exhibit enhanced radiation-induced $^{45}\text{Ca}^{2+}$ efflux at an SAR of 0.05 W/kg, using 147 MHz, AM at 16 Hz. These results confirm that amplitude-modulated radiofrequency radiation can induce responses in cells of nervous tissue origin from widely different animal species, including humans. The results are also consistent with the reports of similar findings in avian and feline brain tissues and indicate the general nature of the phenomenon.

(9) Fesenko, EE, Makar, VR, Novoselova, EG, Sadovnikov, VB, Microwaves and cellular immunity. I. Effect of whole body microwave irradiation on tumor necrosis factor production in mouse cells. *Bioelectrochem Bioenerg* 49(1):29-35, 1999.

Whole body microwave sinusoidal irradiation of male NMRI mice with 8.15-18 GHz (1 Hz within) at a power density of 1 $\mu\text{W}/\text{cm}^2$ caused a significant enhancement of TNF production in peritoneal macrophages and splenic T lymphocytes. Microwave radiation affected T cells, facilitating their capacity to proliferate in response to mitogenic stimulation. The exposure duration necessary for the stimulation of cellular immunity ranged from 5 h to 3 days. Chronic irradiation of mice for 7 days produced the decreasing of TNF production in peritoneal macrophages. The exposure of mice for 24 h increased the TNF production and immune proliferative response, and these stimulatory effects persisted over 3 days after the termination of exposure. Microwave treatment increased the endogenously produced TNF more effectively than did lipopolysaccharide, one of the most potential stimuli of synthesis of this

cytokine. The role of microwaves as a factor interfering with the process of cell immunity is discussed.

(10) Hjollund NH, Bonde JP, Skotte J, Semen analysis of personnel operating military radar equipment. *Reprod Toxicol* 11(6):897, 1997. This is a preliminary survey of semen quality among Danish military personnel operating mobile ground-to-air missile units that use several microwave emitting radar systems. The maximal mean exposure was estimated to be 0.01 mW/cm². The median sperm density of the military personnel was significantly low compared to the references. The difference is either due to chance, uncontrolled bias, or nonthermal effects of transitory microwaves.

(11) Hocking B, Gordon IR, Grain HL, Hatfield GE, Cancer incidence and mortality and proximity to TV towers. *Med J Aust* 165(11-12):601-605, 1996.

(Published erratum appears in *Med J Aust* 166(2):80, 1997.)

OBJECTIVE: To determine whether there is an increased cancer incidence and mortality in populations exposed to radiofrequency radiations from TV towers. **DESIGN:** An ecological study comparing cancer incidence and mortality, 1972-1990, in nine municipalities, three of which surround the TV towers and six of which are further away from the towers. (TV radiofrequency radiation decreases with the square of the distance from the source.) Cancer incidence and mortality data were obtained from the then Commonwealth Department of Human Services and Health. Data on frequency, power, and period of broadcasting for the three TV towers were obtained from the Commonwealth Department of Communications and the Arts. The calculated power density of the radiofrequency radiation in the exposed area ranged from 8.0 microW/cm² near the towers to 0.2 microW/cm² at a radius of 4km and 0.02 microW/cm² at 12 km. **SETTING:** Northern Sydney, where three TV towers have been broadcasting since 1956. **OUTCOME MEASURES:** Rate ratios for leukaemia and brain tumour incidence and mortality, comparing the inner with the outer areas. **RESULTS:** For all ages, the rate ratio for total leukaemia incidence was 1.24 (95% confidence interval [CI], 1.09-1.40). Among children, the rate ratio for leukaemia incidence was 1.58 (95% CI, 1.07-2.34) and for mortality it was 2.32 (95% CI, 1.35-4.01). The rate ratio for childhood lymphatic leukaemia (the most common type) was 1.55 (95% CI, 1.00-2.41) for incidence and 2.74 (95% CI, 1.42-5.27) for mortality. Brain cancer incidence and mortality were not increased. **CONCLUSION:** We found an association between increased childhood leukaemia incidence and mortality and proximity to TV towers.

(12) Ivaschuk OI, Jones RA, Ishida-Jones T, Haggren W, Adey WR, Phillips JL, Exposure of nerve growth factor-treated PC12 rat pheochromocytoma cells to a modulated radiofrequency field at 836.55 MHz: effects on c-jun and c-fos expression. *Bioelectromagnetics* 18(3):223-229, 1997.

Rat PC12 pheochromocytoma cells have been treated with nerve growth factor And then exposed to athermal levels of a packet-modulated radiofrequency field

At 836.55 MHz. This signal was produced by a prototype time-domain multiple-access (TDMA) transmitter that conforms to the North American digital cellular telephone standard. Three slot average power densities were used: 0.09, 0.9, and 9 mW/cm². Exposures were for 20, 40, and 60 min and included an intermittent exposure regimen (20 min on/20 min off), resulting in total incubation times of 20, 60, and 100 min, respectively. Concurrent controls were sham exposed. After extracting total cellular RNA, Northern blot analysis was used to assess the expression of the immediate early genes, c-fos and c-jun, in all cell populations. No change in c-fos transcript levels were detected after 20 min exposure at each field intensity (20 min was the only time period at which c-fos message could be detected consistently). Transcript levels for c-jun were altered only after 20 min exposure to 9 mW/cm² (average 38% decrease).

(13) Kolodynski AA, Kolodynska VV, Motor and psychological functions of school children living in the area of the Skrunda Radio Location Station in Latvia. *Sci Total Environ* 180(1):87-93, 1996.

This paper presents the results of experiments on school children living in the area of the Skrunda Radio Location Station (RLS) in Latvia. Motor function, memory and attention significantly differed between the exposed and control groups. Children living in front of the RLS had less developed memory and attention, their reaction time was slower and their neuromuscular apparatus endurance was decreased.

(14) Kwee S, Raskmark P, Velizarov P. Changes in cellular proteins due to environmental non-ionizing radiation. I. Heat-shock proteins. *Electro- and Magnetobiology* 20: 141-152, 2001.

This paper describes the effect of weak microwave fields on the amounts of heat-shock proteins in cell cultures at various temperatures. The field was generated by signal simulation of the Global System for Mobile communications (GSM) of 960 Mhz, used in portable phones. Transformed human epithelial amnion (AMA) cells, growing on glass coverslips, were exposed in a transverse electromagnetic (TEM) cell to a microwave field, generating a specific absorption rate (SAR) of 2.1 mW.kg⁻¹ in the cells. Exposure temperatures were 35, 37, and 40 Å 0.1°C, respectively, and the exposure time was 20 min. The heat-shock proteins Hsp-70 and Hsp-27 were detected by immuno-fluorescence. Higher amounts of Hsp-70 were present in the cells exposed at 35 and 37°C than in the sham-exposed cells. These effects can be considered to be athermal, since the field strength was much lower than the safety standard for absence of heat generation by microwave fields. There was no significant response in the case of Hsp-27.

(15) Lebedeva NN, Sulimov AV, Sulimova OP, Kotrovskaya TI, Gailus T, Cellular phone electromagnetic field effects on bioelectric activity of human brain. *Crit Rev Biomed Eng* 28(1-2):323-337, 2000. 24 volunteers participated in the experiments. The investigation of EEG reactions to cellular phone (EMF frequency 902.4 MHz and intensity 0.06 mW/cm²) was conducted. Two

experiments were performed with each subject--cellular phone exposure and Placebo Duration of the experiment was 60 min: 15 min--background; 15 min--EMF exposure or Placebo; 30 min—after exposure. EEG was recorded in 16 standard leads with "eyes open" and "eyes closed". Special software with non-linear dynamics was developed for EEG analyses. One parameter, multichannel (global) correlation dimension, was calculated. The changes of these parameters can be evidence of brain functional state changes. As a result of EEG record processing, a significant increase of global correlation dimension during the exposure and after exposure period was discovered, more pronounced in the case of "eyes closed". That can be viewed as the manifestation of cortex activation under phone EMF exposure.

(16) Magras, IN, Xenos, TD, RF radiation-induced changes in the prenatal development of mice. *Bioelectromagnetics* 18(6):455-461, 1997.

The possible effects of radiofrequency (RF) radiation on prenatal development has been investigated in mice. This study consisted of RF level measurements and in vivo experiments at several places around an "antenna park." At these locations RF power densities between 168 nW/cm² and 1053 nW/cm² were measured. Twelve pairs of mice, divided in two groups, were placed in locations of different power densities and were repeatedly mated five times. One hundred eighteen newborns were collected. They were measured, weighed, and examined macro- and microscopically. A progressive decrease in the number of newborns per dam was observed, which ended in irreversible infertility. The prenatal development of the newborns, however, evaluated by the crown-rump length, the body weight, and the number of the lumbar, sacral, and coccygeal vertebrae, was improved.

(17) Mann, K, Wagner, P, Brunn, G, Hassan, F, Hiemke, C, Roschke, J, Effects of pulsed high-frequency electromagnetic fields on the neuroendocrine system. *Neuroendocrinology* 67(2):139-144, 1998.

The influence of pulsed high-frequency electromagnetic fields emitted from a circularly polarized antenna on the neuroendocrine system in healthy humans was investigated (900 MHz electromagnetic field, pulsed with 217 Hz, average power density 0.02 mW/cm²). Nocturnal hormone profiles of growth hormone (GH), cortisol, luteinizing hormone (LH) and melatonin were determined under polysomnographic control. An alteration in the hypothalamo-pituitary-adrenal axis activity was found with a slight, transient elevation in the cortisol serum level immediately after onset of field exposure which persisted for 1 h. For GH, LH and melatonin, no significant effects were found under exposure to the field compared to the placebo condition, regarding both total hormone production during the entire night and dynamic characteristics of the secretion pattern. Also the evaluation of the sleep EEG data revealed no significant alterations under field exposure, although there was a trend to an REM suppressive effect. The results indicate that weak high-frequency electromagnetic fields have no effects

on nocturnal hormone secretion except for a slight elevation in cortisol production which is transient, pointing to an adaptation of the organism to the stimulus.

(18) Michelozzi P, Ancona C, Fusco D, Forastiere F, Perucci CA, Risk of leukemia and residence near a radio transmitter in Italy. *Epidemiology* 9 (Suppl) 354p, 1998.

We conducted a small area study to investigate a cluster of leukemia near a high power radio-transmitter in a peripheral area of Rome. The leukemia mortality within 3.5 km (5,863 inhabitants) was higher than expected (SMR=2.5, 95% confident interval 1.07-4.83); the excess was due to a significant higher mortality among men (7 cases observed, SMR=3.5). The results of the Stone's test, after adjusting for socio-economic confounding, showed a significant decline in risk with distance from the transmitter only among men ($p=0.005$), whereas the p -value for both sexes was $p=0.07$.

(19) Michelozzi P, Capon A, Kirchmayer U, Forastiere F, Biggeri A, Barca A, Perucci CA. Adult and childhood leukemia near a high-power radio station in Rome, Italy. *Am J Epidemiol* 155(12):1096-1103, 2002.

Some recent epidemiologic studies suggest an association between lymphatic and hematopoietic cancers and residential exposure to high-frequency electromagnetic fields (100 kHz to 300 GHz) generated by radio and television transmitters. Vatican Radio is a very powerful station located in a northern suburb of Rome, Italy. In the 10-km area around the station, with 49,656 residents (in 1991), leukemia mortality among adults (aged >14 years; 40 cases) in 1987-1998 and childhood leukemia incidence (eight cases) in 1987-1999 were evaluated. The risk of childhood leukemia was higher than expected for the distance up to 6 km from the radio station (standardized incidence rate = 2.2, 95% confidence interval: 1.0, 4.1), and there was a significant decline in risk with increasing distance both for male mortality ($p = 0.03$) and for childhood leukemia ($p = 0.036$). The study has limitations because of the small number of cases and the lack of exposure data. Although the study adds evidence of an excess of leukemia in a population living near high-power radio transmitters, no causal implication can be drawn. There is still insufficient scientific knowledge, and new epidemiologic studies are needed to clarify a possible leukemogenic effect of residential exposure to radio frequency radiation.

(20) Navakatikian MA, Tomashevskaya LA, Phasic behavioral and endocrine effects of microwaves of nonthermal intensity. In "Biological Effects of Electric and Magnetic Fields, Volume 1," D.O. Carpenter (ed) Academic Press, San Diego, CA, 1994, pp.333-342.

Microwaves at nonthermal levels are able to induce behavioral and endocrine changes at low power densities (0.01-0.1 mW/cm²). Our studies have demonstrated several phases of inhibition and activation. We suggest that inhibition of behavior by microwaves has many mechanisms depending on the

strength and duration of exposure, and most inhibitory effects from direct actions on the nervous system. Activation, on the other hand, is correlated well with decreases in serum concentrations of testosterone and insulin. CW microwaves, however, have no influence on the secretion of insulin.

(21) Novoselova, EG, Fesenko, EE, Makar, VR, Sadovnikov, VB, Microwaves and cellular immunity. II. Immunostimulating effects of microwaves and naturally occurring antioxidant nutrients. *Bioelectrochem Bioenerg* 49(1):37-41, 1999.

The effect of 8.15-18 GHz (1 Hz within) microwave radiation at a power density of 1 microW/cm² on the tumor necrosis factor (TNF) production and immune response was tested. A single 5 h whole-body exposure induced a significant increase in TNF production in peritoneal macrophages and splenic T cells. The mitogenic response in T lymphocytes increased after microwave exposure. The activation of cellular immunity was observed within 3 days after exposure. The diet containing lipid-soluble nutrients (beta-carotene, alpha-tocopherol and ubiquinone Q9) increased the activity of macrophages and T cells from irradiated mice. These results demonstrate that irradiation with low-power density microwaves stimulates the immune potential of macrophages and T cells, and the antioxidant treatment enhances the effect of microwaves, in particular at later terms, when the effect of irradiation is reduced.

(22) Persson BRR, Salford LG, Brun A, Blood-brain barrier permeability in rats exposed to electromagnetic fields used in wireless communication. *Wireless Network* 3:455-461, 1997.

Biological effects of radio frequency electromagnetic fields (EMF) on the blood-brain barrier (BBB) have been studied in Fischer 344 rats of both sexes. The rats were not anesthetised during the exposure. The brains were perfused with saline for 3-4 minutes, and thereafter perfusion fixed with 4% formaldehyde for 5-6 minutes. Whole coronal sections of the brains were dehydrated and embedded in paraffin and sectioned at 5 micrometers. Albumin and fibinogen were demonstrated immunochemically and classified as normal versus pathological leakage. In the present investigation we exposed male and female Fischer 344 rats in a Transverse Electromagnetic Transmission line camber to microwaves of 915 MHz as continuous wave (CW) and pulse-modulated with different pulse power and at various time intervals. The CW-pulse power varied from 0.001 W to 10 W and the exposure time from 2 min to 960 min. In each experiment we exposed 4-6 rats with 2-4 controls randomly placed in excited and non-excited TEM cells, respectively. We have in total investigated 630 exposed rats at various modulation frequencies and 372 controls. The frequency of pathological rats is significantly increased ($P < 0.0001$) from 62/372 (ratio 0.17 ± 0.02) for control rats to 244/630 (ratio: 0.39 ± 0.043) in all exposed rats. Grouping the exposed animals according to the level or specific absorption energy (J/kg) give significant difference in all levels above 1.5 J/kg. The exposure was 915 MHz microwaves either pulse modulated (PW) at 217 Hz with 0.57 ms pulse width, at 50 Hz with 6.6 ms pulse width or continuous wave (CW). The frequency of pathological rats

(0.17) among controls in the various groups is not significantly different. The frequency of pathological rats was 170/480 (0.35 ± 0.03) among rats exposed to pulse modulated (PW) and 74/149 (0.50 ± 0.07) among rats exposed to continuous wave exposure (CW). These results are both highly significantly different to their corresponding controls ($p < 0.0001$) and the frequency of pathological rats after exposure to pulsed radiation (PW) is significantly less ($p < 0.002$) than after exposure to continuous wave radiation (CW).

(23) Phillips, J.L., Ivaschuk, O., Ishida-Jones, T., Jones, R.A., Campbell-Beachler, M. and Haggren, W. DNA damage in Molt-4 T- lymphoblastoid cells exposed to cellular telephone radiofrequency fields in vitro. *Bioelectrochem. Bioenerg.* 45:103-110, 1998.

Molt-4 T-lymphoblastoid cells have been exposed to pulsed signals at cellular telephone frequencies of 813.5625 MHz (iDEN signal) and 836.55 MHz (TDMA signal). These studies were performed at low SAR (average = 2.4 and 24 microwatt/g for iDEN and 2.6 and 26 microwatt/g for TDMA) in studies designed to look for athermal RF effects. The alkaline comet, or single cell gel electrophoresis, assay was employed to measure DNA single-strand breaks in cell cultures exposed to the radiofrequency (RF) signal as compared to concurrent sham-exposed cultures. Tail moment and comet extent were calculated as indicators of DNA damage. Statistical differences in the distribution of values for tail moment and comet extent between exposed and control cell cultures were evaluated with the Kolmogorov-Smirnoff distribution test. Data points for all experiments of each exposure condition were pooled and analyzed as single groups. It was found that: 1) exposure of cells to the iDEN signal at an SAR of 2.4 microwatt/g for 2 h or 21 h significantly decreased DNA damage; 2) exposure of cells to the TDMA signal at an SAR of 2.6 microwatt/g for 2 h and 21 h significantly decreased DNA damage; 3) exposure of cells to the iDEN signal at an SAR of 24 microwatt/g for 2 h and 21 h significantly increased DNA damage; 4) exposure of cells to the TDMA signal at an SAR of 26 microwatt/g for 2 h significantly decreased DNA damage. The data indicate a need to study the effects of exposure to RF signals on direct DNA damage and on the rate at which DNA damage is repaired.

(24) Pologea-Moraru R, Kovacs E, Iliescu KR, Calota V, Sajin G. The effects of low level microwaves on the fluidity of photoreceptor cell membrane. *Bioelectrochemistry* 56(1-2):223-225, 2002. Due to the extensive use of electromagnetic fields in everyday life, more information is required for the detection of mechanisms of interaction and the possible side effects of electromagnetic radiation on the structure and function of the organism. In this paper, we study the effects of low-power microwaves (2.45 GHz) on the membrane fluidity of rod photoreceptor cells. The retina is expected to be very sensitive to microwave irradiation due to the polar character of the photoreceptor cells [Biochim. Biophys. Acta 1273 (1995) 217] as well as to its high water content [Stud. Biophys. 81 (1981) 39].

(25) Salford LG, Brun AR, Eberhardt JL, Malmgren L, Persson BRR, Nerve cell damage in mammalian brain after exposure to microwaves from GSM mobile phones. *Environ Health Persp Online* January 29, 2003.

The possible risks of radio-frequency electromagnetic fields for the human body is a growing concern for the society. We have earlier shown that weak pulsed microwaves give rise to a significant leakage of albumin through the blood-brain barrier (BBB). Now we have investigated whether a pathological leakage over the BBB might be combined with damage to the neurons. Three groups of each 8 rats were exposed for 2 hours to GSM mobile phone electromagnetic fields of different strengths. We found, and present here for the first time, highly significant ($p < 0.002$) evidence for neuronal damage in both the cortex, the hippocampus and the basal ganglia in the brains of exposed rats.

(26) Santini R, Santini P, Danze JM, Le Ruz P, Seigne M. Study of the health of people living in the vicinity of mobile phone base stations: I. Influence of distance and sex. *Pathol Biol (Paris)* 50(6):369-373, 2002. [Article in French]

A survey study using questionnaire was conducted in 530 people (270 men, 260 women) living or not in vicinity of cellular phone base stations, on 18 Non Specific Health Symptoms. Comparisons of complaints frequencies (CHI-SQUARE test with Yates correction) in relation with distance from base station and sex, show significant ($p < 0.05$) increase as compared to people living > 300 m or not exposed to base station, till 300 m for tiredness, 200 m for headache, sleep disturbance, discomfort, etc. 100 m for irritability, depression, loss of memory, dizziness, libido decrease, etc. Women significantly more often than men ($p < 0.05$) complained of headache, nausea, loss of appetite, sleep disturbance, depression, discomfort and visual perturbations. This first study on symptoms experienced by people living in vicinity of base stations shows that, in view of radioprotection, minimal distance of people from cellular phone base stations should not be < 300 m.

(27) Schwartz JL, House DE, Mealing GA, Exposure of frog hearts to CW or amplitude-modulated VHF fields: selective efflux of calcium ions at 16 Hz. *Bioelectromagnetics* 11(4):349-358, 1990. Isolated frog hearts were exposed for 30-min periods in a Crawford cell to a 240-MHz electromagnetic field, either continuous-wave or sinusoidally modulated at 0.5 or 16 Hz. Radiolabeled with calcium (^{45}Ca), the hearts were observed for movement of Ca^{2+} at calculated SARs of 0.15, 0.24, 0.30, 0.36, 1.50, or 3.00 mW/kg. Neither CW radiation nor radiation at 0.5 Hz, which is close to the beating frequency of the frog's heart, affected movement of calcium ions. When the VHF field was modulated at 16 Hz, a field-intensity-dependent change in the efflux of calcium ions was observed. Relative to control values, ionic effluxes increased by about 18% at 0.3 mW/kg (P less than .01) and by 21% at 0.15 mW/kg (P less than .05), but movement of ions did not change significantly at other rates of energy deposition. These data

indicate that the intact myocardium of the frog, akin to brain tissue of neonatal chicken, exhibits movement of calcium ions in response to a weak VHF field that is modulated at 16 Hz.

(28) Somosy Z, Thuroczy G, Kubasova T, Kovacs J, Szabo LD, Effects of modulated and continuous microwave irradiation on the morphology and cell surface negative charge of 3T3 fibroblasts. *Scanning Microsc* 5(4):1145-1155, 1991. Mouse embryo 3T3 cells were irradiated with 2450 MHz continuous and low frequency (16 Hz) square modulated waves of absorbed energy ranging from 0.0024 to 2.4 mW/g. The low frequency modulated microwave irradiation yielded more morphological cell changes than did the continuous microwave fields of the same intensity. The amount of free negative charges (cationized ferritin binding) on cell surfaces decreased following irradiation by modulated waves but remained unchanged under the effect of a continuous field of the same dose. Modulated waves of 0.024 mW/g dose increased the ruffling activity of the cells, and caused ultrastructural alteration in the cytoplasm. Similar effects were experienced by continuous waves at higher (0.24 and 2.4 mW/g) doses.

(29) Stagg RB, Thomas WJ, Jones RA, Adey WR, DNA synthesis and cell proliferation in C6 glioma and primary glial cells exposed to a 836.55 MHz modulated radiofrequency field. *Bioelectromagnetics* 18(3):230-236, 1997.

We have tested the hypothesis that modulated radiofrequency (RF) fields may act as a tumor-promoting agent by altering DNA synthesis, leading to increased cell proliferation. In vitro tissue cultures of transformed and normal rat glial cells were exposed to an 836.55 MHz, packet-modulated RF field at three power densities: 0.09, 0.9, and 9 mW/cm², resulting in specific absorption rates (SARs) ranging from 0.15 to 59 μ W/g. TEM-mode transmission-line cells were powered by a prototype time-domain multiple-access (TDMA) transmitter that conforms to the North American digital cellular telephone standard. One sham and one energized TEM cell were placed in standard incubators maintained at 37 degrees C and 5% CO₂. DNA synthesis experiments at 0.59-59 μ W/g SAR were performed on log-phase and serum-starved semiquiescent cultures after 24 h exposure. Cell growth at 0.15-15 μ W/g SAR was determined by cell counts of log-phase cultures on days 0, 1, 5, 7, 9, 12, and 14 of a 2 week protocol. Results from the DNA synthesis assays differed for the two cell types. Sham-exposed and RF-exposed cultures of primary rat glial cells showed no significant differences for either log-phase or serum-starved condition. *C6 glioma cells exposed to RF at 5.9 μ W/g SAR (0.9 mW/cm²) exhibited small (20-40%) significant increases in 38% of [3H]thymidine incorporation experiments.* Growth curves of sham and RF-exposed cultures showed no differences in either normal or transformed glial cells at any of the power densities tested. Cell doubling times of C6 glioma cells [sham (21.9 +/- 1.4 h) vs. field (22.7 +/- 3.2 h)] also demonstrated no significant differences that could be attributed to altered DNA synthesis rates. Under these conditions, this modulated RF field did not increase cell proliferation of normal or transformed cultures of glial origin.

(30) Stark KD, Krebs T, Altpeter E, Manz B, Griot C, Abelin T, Absence of

chronic effect of exposure to short-wave radio broadcast signal on salivary melatonin concentrations in dairy cattle. *J Pineal Res* 22(4):171-176, 1997.

A pilot study was conducted to investigate the influence of electromagnetic fields in the short-wave range (3-30 MHz) radio transmitter signals on salivary melatonin concentration in dairy cattle. The hypothesis to be tested was whether EMF exposure would lower salivary melatonin concentrations, and whether removal of the EMF source would be followed by higher concentration levels. For this pilot study, a controlled intervention trial was designed. Two commercial dairy herds at two farms were compared, one located at a distance of 500 m (exposed), the other at a distance of 4,000 m (unexposed) from the transmitter. At each farm, five cows were monitored with respect to their salivary melatonin concentrations over a period of ten consecutive days. Saliva samples were collected at two-hour intervals during the dark phase of the night. As an additional intervention, the short-wave transmitter was switched off during three of the ten days (off phase). The samples were analyzed using a radioimmunoassay. The average nightly field strength readings were 21-fold greater on the exposed farm (1.59 mA/m) than on the control farm (0.076 mA/m). The mean values of the two initial nights did not show a statistically significant difference between exposed and unexposed cows. Therefore, a chronic melatonin reduction effect seemed unlikely. ***However, on the first night of re-exposure after the transmitter had been off for three days, the difference in salivary melatonin concentration between the two farms (3.89 pg/ml, CI: 2.04, 7.41) was statistically significant, indicating a two- to seven-fold increase of melatonin concentration. Thus, a delayed acute effect of EMF on melatonin concentration cannot completely be excluded.*** However, results should be interpreted with caution and further trials are required in order to confirm the results.

(31) Tattersall JE, Scott IR, Wood SJ, Nettell JJ, Bevir MK, Wang Z, Somasiri NP, Chen X. Effects of low intensity radiofrequency electromagnetic fields on electrical activity in rat hippocampal slices. *Brain Res* 904(1):43-53, 2001. Slices of rat hippocampus were exposed to 700 MHz continuous wave radiofrequency (RF) fields (25.2-71.0 V m⁻¹, 5-15 min exposure) in a stripline waveguide. At low field intensities, the predominant effect on the electrically evoked field potential in CA1 was a potentiation of the amplitude of the population spike by up to 20%, but higher intensity fields could produce either increases or decreases of up to 120 and 80%, respectively, in the amplitude of the population spike. To eliminate the possibility of RF-induced artefacts due to the metal stimulating electrode, the effect of RF exposure on spontaneous epileptiform activity induced in CA3 by 4-aminopyridine (50-100 µM) was investigated. Exposure to RF fields (50.0 V m⁻¹) reduced or abolished epileptiform bursting in 36% of slices tested. The maximum field intensity used in these experiments, 71.0 V m⁻¹, was calculated to produce a specific absorption rate (SAR) of between 0.0016 and 0.0044 W kg⁻¹ in the slices. Measurements with a Luxtron fibreoptic probe confirmed that there was no detectable temperature change (+/-0.1 degrees C) during a 15 min exposure to this field intensity. Furthermore, imposed

temperature changes of up to 1 degrees C failed to mimic the effects of RF exposure. These results suggest that low-intensity RF fields can modulate the excitability of hippocampal tissue in vitro in the absence of gross thermal effects. The changes in excitability may be consistent with reported behavioural effects of RF fields.

(32) Vangelova K, Israel M, Mihaylov S. The effect of low level radiofrequency electromagnetic radiation on the excretion rates of stress hormones in operators during 24-hour shifts. *Cent Eur J Public Health* 10(1-2):24-28, 2002. The aim of the study was to investigate the effect of long term exposure to low level radiofrequency (RF) electromagnetic (EM) radiation on the excretion rates of stress hormones in satellite station operators during 24-hour shifts. Twelve male operators at a satellite station for TV communications and space research were studied during 24-hour shifts. Dosimetric evaluation of the exposure was carried out and showed low level exposure with specific absorption of 0.1127 J.kg⁻¹. A control group of 12 unexposed male operators with similar job task and the same shift system were studied, too. The 11-oxycorticosteroids (11-OCS), adrenaline and noradrenaline were followed by spectrofluorimetric methods on 3-hour intervals during the 24-hour shifts. The data were analyzed by tests for interindividual analysis, Cosinor analysis and analysis of variance (ANOVA). Significant increase in the 24-hour excretion of 11-OCS and disorders in its circadian rhythm, manifested by increase in the mesor, decrease in the amplitude and shift in the acrophase were found in the exposed operators. The changes in the excretion rates of the catecholamines were significant and showed greater variability of both variables. The long term effect of the exposure to low-level RF EM radiation evoked pronounced stress reaction with changes in the circadian rhythm of 11-OCS and increased variability of catecholamines secretion. The possible health hazards associated with observed alteration in the stress system need to be clarified by identification of their significance and prognostic relevance.

(33) Velizarov, S, Raskmark, P, Kwee, S, The effects of radiofrequency fields on cell proliferation are non-thermal. *Bioelectrochem Bioenerg* 48(1):177-180, 1999.

The number of reports on the effects induced by radiofrequency (RF) electromagnetic fields and microwave (MW) radiation in various cellular systems is still increasing. Until now no satisfactory mechanism has been proposed to explain the biological effects of these fields. One of the current theories is that heat generation by RF/MW is the cause, in spite of the fact that a great number of studies under isothermal conditions have reported significant cellular changes after exposure to RF/MW. Therefore, this study was undertaken to investigate which effect MW radiation from these fields in combination with a significant change of temperature could have on cell proliferation. The experiments were performed on the same cell line, and with the same exposure system as in a previous work [S. Kwee, P. Raskmark, Changes in cell proliferation due to environmental non-ionizing radiation: 2. Microwave radiation, *Bioelectrochem. Bioenerg.*, 44 (1998), pp. 251-255]. The field was generated by signal simulation of the Global System for Mobile communications (GSM) of 960 MHz. Cell cultures, growing in microtiter plates, were exposed in a specially constructed chamber, a Transverse Electromagnetic (TEM) cell. The Specific Absorption Rate (SAR) value for each cell well was calculated for this exposure system. However, in this study the cells were exposed to the field at a higher or lower temperature than the temperature in the field-free

incubator i.e., the temperature in the TEM cell was either 39 or 35 +/- 0.1 degrees C. The corresponding sham experiments were performed under exactly the same experimental conditions. The results showed that there was a significant change in cell proliferation in the exposed cells in comparison to the non-exposed (control) cells at both temperatures. On the other hand, no significant change in proliferation rate was found in the sham-exposed cells at both temperatures. This shows that biological effects due to RF/MW cannot be attributed only to a change of temperature. Since the RF/MW induced changes were of the same order of magnitude at both temperatures and also comparable to our previous results under isothermal conditions at 37 degrees C, cellular stress caused by electromagnetic fields could initiate the changes in cell cycle reaction rates. It is widely accepted that certain classes of heat-shock proteins are involved in these stress reactions.

(34) Veyret B, Bouthet C, Deschaux P, de Seze R, Geffard M, Jousset-Dubien J, le Diraison M, Moreau JM, Caristan A, Antibody responses of mice exposed to low-power microwaves under combined, pulse-and-amplitude modulation.

***Bioelectromagnetics* 12(1):47-56, 1991.** Irradiation by pulsed microwaves (9.4 GHz, 1 microsecond pulses at 1,000/s), both with and without concurrent amplitude modulation (AM) by a sinusoid at discrete frequencies between 14 and 41 MHz, was assessed for effects on the immune system of Balb/C mice. The mice were immunized either by sheep red blood cells (SRBC) or by glutaric-anhydride conjugated bovine serum albumin (GA-BSA), then exposed to the microwaves at a low rms power density (30 microW/cm²; whole-body-averaged SAR approximately 0.015 W/kg). Sham exposure or microwave irradiation took place during each of five contiguous days, 10 h/day. The antibody response was evaluated by the plaque-forming cell assay (SRBC experiment) or by the titration of IgM and IgG antibodies (GA-BSA experiment). In the absence of AM, the pulsed field did not greatly alter immune responsiveness. In contrast, exposure to the field under the combined-modulation condition resulted in significant, AM-frequency-dependent augmentation or weakening of immune responses.

(35) Wolke S, Neibig U, Elsner R, Gollnick F, Meyer R, Calcium homeostasis of isolated heart muscle cells exposed to pulsed high-frequency electromagnetic fields. *Bioelectromagnetics* 17(2):144-153, 1996.

The intracellular calcium concentration ($[Ca^{2+}]_i$) of isolated ventricular cardiac myocytes of the guinea pig was measured during the application of pulsed high-frequency electromagnetic fields. The high-frequency fields were applied in a transverse electromagnetic cell designed to allow microscopic observation of the myocytes during the presence of the high-frequency fields. The $[Ca^{2+}]_i$ was measured as fura-2 fluorescence by means of digital image analysis. Both the carrier frequency and the square-wave pulse-modulation pattern were varied during the experiments (carrier frequencies: 900, 1,300, and 1,800 MHz pulse modulated at 217Hz with 14 percent duty cycle; pulsation pattern at 900 MHz: continuous wave, 16 Hz, and 50 Hz modulation with 50 percent duty cycle and 30 kHz modulation with 80 percent duty cycle). The mean specific absorption rate (SAR) values in the solution were within one order of magnitude of **1 mW/kg**. They varied depending on the applied carrier frequency

and pulse pattern. The experiments were designed in three phases: 500 s of sham exposure, followed by 500 s of field exposure, then chemical stimulation without field. The chemical stimulation (K⁺ -depolarization) indicated the viability of the cells. The K⁺ depolarization yielded a significant increase in [Ca²⁺]_i. Significant differences between sham exposure and high-frequency field exposure were not found except when a very small but statistically significant difference was detected in the case of 900 MHz/50 Hz. However, this small difference was not regarded as a relevant effect of the exposure.