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Literature study

on possible long-term effects of high-frequency



Preliminary remarks

Topic of this report are studies on possible long-term effects of high-frequency fields; of particular interest for the evaluation of each individual study is its methodical approach.

Published literature on the topic is listed and reviewed. Primarily, studies on GSM signals, but possibly also on CDMA signals will be dealt with. Where no studies on this topic complex are available, data from investigations into other comparable high-frequency fields can be noteworthy. Only long-term effects from animal experiments will be discussed, i.e. effects occurring after at least 90-days exposure.

The following questions/aspects seem to be crucial:

- What evidence is there of long-term effects in the animal?
- an evaluation of the studies in view of the experimental design and biological/medical endpoints
- an evaluation of the studies in regard to health relevance and/or risk assessment.

Introduction

The electromagnetic spectrum can be divided into ionising and non-ionising radiation by means of the transmitted energy. It consists of quite different phenomena, like for example radio, light, in the ionising range x-ray radiation and cosmic radiation occurring in nature. In the radio-frequency range (RF) definitely non-ionising energies are transmitted, i.e.

and conclusions

electromagnetic fields particularly of mobile radio (GSM)

energies (< 12 eV) arithmetically too small to break chemical compounds thus altering the genetic substance. The emitted electromagnetic RF signals have numerous origins: Radio broadcasting, television, radar, directional radio and mobile radio are some of the possible sources, but also in industry (drying and welding plants) and in medicine (diathermal devices) high-frequency electromagnetic fields (HF-EMF) are used. Further, EMF naturally develop where electric voltage exists and electric current flows.

Currently, there is an ongoing discussion about possible health hazards caused by electromagnetic exposure; above all, HF-EMF are suspected to be a potential source of health detriments because of the widespread mobile radio nets (800 MHz–2 GHz). In contrast, the long-existing broadcast radio, television or radio signals mostly remain completely unnoticed. Electromagnetic field effects are ubiquitous also in the private sector (domestic environment, workplace); a huge number of electric appliances has already been tested, for example monitors (video, computer) or microwave ovens. However, nowadays for all electric (electronic) devices shielding-related safety guidelines are defined. Thus, according to present knowledge and scientific experience health impairments in humans or environmental detriments – provided the device is properly applied – are excluded.

Until now, scientific long-term studies on the HF-EMF range are lacking; already

published studies partially are not acceptable because of inadequacies in implementation.

First, we will provide a comprehensive analysis of research gaps in the area of health risk assessment of long-term effects of high-frequency electromagnetic fields, especially those of mobile radio (primarily GSM signals) which will be identified and evaluated based on available literature data.

Following aspects seem to be of importance, here:

- What evidence is there of long-term effects of EMF exposure in animal experiments?
- How are studies to be evaluated under the aspect of experimental design and biological/medical endpoints?
- How relevant are study results for human health and/or for the risk assessment towards chronic EMF exposure?

Criteria for the evaluation of literature

Included were only scientific publications taken from peer reviewed journals dealing with studies on long-term effects (exposure > 90 days) of high-frequency electromagnetic fields. Technical aspects of exposure/dosimetry are not considered, though we will point to corresponding texts (Valberg 1995, Gauger et al. 1999).

For characterising exposure of test subjects usually the specific absorption rate (SAR) is used, averaged as whole body ab-

sorption rate. This quantity describes the energy absorbed by tissue per mass unit, not uniformly distributed in the body of the test subject but dependent on frequency. In certain body areas high absorption rates, so-called hot spots, can occur (dependent on water contents, conductivity and geometry) that scarcely are paid attention to by literature surveys. Knowledge about the specific absorption rate is a fundamental condition for evaluating exposure set-ups and/or interaction mechanisms of field exposure. The SAR must be examined for risk assessment – particularly locally for the exposed head/brain area – at all frequencies, in regard to the used modulation type and different device configurations.

For interactions between EMF and biological structures not the whole body average SAR value, but the local SAR distribution in the body is important. Therefore, the average SAR values being the basis of experiments in laboratory animals should not be used for EMF exposure risk assessment in humans at defined frequencies by way of extrapolating different mass proportions.

Besides by frequency, body measurements and electric tissue data, the specific absorption rate is also determined by body stance and body orientation within the field. Further, dosimetry studies in mice have shown that resulting whole body exposure values may vary strongly and that to this reason in differ-



ent tissues hugely different temperature values can occur (Swicord et al. 1999).

Particularly in regard to this thermal EMF effect and also to the so-called athermal exposure, i.e. SAR values that do not lead to tissue heating through compensation mechanisms of the body (for example higher heat reduction through increased circulation), one must additionally point to physiological differences in thermoregulation of different species (animal/human) regarding extrapolation of animal experiment results.

At an averaged whole body SAR of 1-4 W/kg an 'average human' temperature increase of about 1°C develops within 30 minutes; in other words, the limit value defined by the ICNIRP (International Commission for Non-Ionizing Radiation Protection) and made obligatory by law of 80 mW/kg (= 1/50 of 4 W/kg) offers sufficient safety concerning local peak absorption rates, even if so-called 'non-average' humans (i.e. sick and old people, pregnant women, children) are exposed. An additional important characteristic of mobile radio nets is the self-regulation of transmission power in mobile radio systems, i.e. only the minimum required power is emitted. However, in assessing possible health risks of mobile radio signals it is a must to expose to maximum permitted transmission power, even if it is rarely applied in daily operations.

Therefore – and as we know about thermal effects of EMF – in this literature survey non-thermal biological effects and/or evidence of health risks for humans through athermal effects in animal experiments with chronical GSM exposure were put into the foreground. Here, whenever possible we referred to studies on effects of GSM mobile radio systems. Where there were no results available on the mentined topics, we referred to other studies.

Studies on possible carcinogenesis through HF-EMF exposure

The multi-phase process of carcinogenesis consisting of initiation, promotion and progression after a latency period of possibly several years even up to decades via the initial transformation of the normal cell leads to a clinically manifest tumor. At the start of this process the irreversibly impaired cell still is controlled by normal tissue, but during promotion the proliferation stimulus for the clonal multiplying of transformed cells takes effect; at first, so-called benign tumors develop. During progression an increased transformation of benign into malign tumors occurs characterised among other things by increasing autonomy and a higher metastasis development potential.

In connection with the assumption that EMF have carcinogenous, co-carcinogenous or promoting effects in particular chromosome alterations (single/double strand breaks of DNA) proven in in vitro tests under EMF exposure by Lai and Singh (1995, 1996, 1997) and/or epidemiological EMF experiments (review f.e. in Savitz 1993) in humans (exposure in domestic environment or at workplace) are referred to.

However, the results of epidemiological studies in part are contradictory, and the relevance of existing experimental studies is particularly small for GSM signals. The analyses of Lai and Singh (1995, 1996) on chromosome single/double strand breaks in rat brain cells being exposed for two hours at 2450 MHz with a whole body SAR of 1.2 W/kg obviously are not suited for HF-EMF studies in the mobile radio range, too, since field exposure here amounted to 15 times the permitted limit value and local thermal effects may possibly be responsible for the DNA strand breaks.

In vitro studies of Malyapa and co-workers (1997a) could not replicate DNA strand breaks at 2450 MHz (SAR: 0.7-1.9 W/kg);

studies in the frequency range of 835.62 MHz (FMCW signal) and/or 847.74 MHz (CDMA signal) with a 0.6 W/kg SAR did not cause any detectable genetic alterations (Malypa et al. 1997b).

Cytogenetic effects on human leucocytes caused by GSM signals (935.2 MHz, 0.4 W/kg SAR) alone or combined with mitomycin C were examined by Maes et al. (1997) by means of chromosome aberration tests, of a sister chromatid exchange (SCE) test and the alkaline comet assay. Direct cytogenetic alterations caused by field exposure were not determined by these methods, in combination with mitomycin A, however, in some cases a slight increase of the SCE rate was detected.

Exposure tests (1 hour) applying 1.6 GHz signals (continuous wave or 11 Hz pulsed) of iridium satellite phones showed an increased development of c-fos messenger DNA in the mouse brain. This neuronally limited alteration also observed under stress and/or at the occurrence of neuronal stimuli were found only at 30 times exceeded average maximum whole body exposure and/or 6 times exceeded exposure peak values. Therefore, the authors assume an effect caused by the immobilisation of the animals and by local heating not being relevant in risk assessment of HF exposures of mobile radio nets and/or satellite phones (Morrissey et al. 1999).

According to the 3-phase model of tumor development, studies on EMF carcinogenesis in laboratory animals in compliance to the study objectives (initiation/promotion/progression) may be divided as follows:

Experimental studies on the possible carcinogenous initiation caused by HF-EMF exposure

In 1981 Mc Ree et al. examined the sister chromatid exchange in bone marrow cells after EMF exposure (2450 MHz, SAR:

21 W/kg) and found no evidence of mutagenous effects of field exposure after 28 days with 8 hours of exposure per day in female CD1 mice.

Sarkar and colleagues (1994) showed DNA alterations (point mutation, base sequence changes) in the brain and in the testicles of Swiss mice being exposed for 2 hours per day for 120, 150 and/or 200 days (2450 MHz, SAR: 1.18 W/kg). In contrast, in C3H/HeJ mice there were found no changes in micronuclei tests in bone marrow and in peripheral erythrocytes after 18 months exposure (20 hours per day, 7 days per week, 2450 MHz, SAR: 1.0 W/kg) (Vijayalaxmi et al. 1997).

Chou et al. (1992) examined the effects of a lifelong pulsed EMF exposure (2450 MHz) in SD rats; at the start of the study an average specific absorption rate of 0.4 W/kg (200 g body weight) was identified. Though no increased tumor rates were observed, the incidence of malign neoplasms in the lifelong field exposed group of laboratory rodents was statistically significantly increased. Nevertheless, in the view of the authors, the biological relevance of this finding remains questionable, particularly since the total number of animals carrying benign and malign tumors, as well as the incidence of neoplasms in the individual tissues/organs did not differ significantly. Further, the authors compared the incidence of malign tumors of the exposure group to information taken from literature, i.e. to the malign tumor incidence in non-treated Sprague-Dawley rats (historical control animals) also held under SPF conditions, and could not find statistically noticeable incidence differences towards the EMF exposure group. Thus, Chou and colleagues conclude that, in summary, the pathological results of their study do not point to EMF-induced effects.

Frei et al. (1998) during their 18-months study in 100 C3H/HeJ mice (2450 MHz, 18 months, 7 days per week, 20 hours per day, SAR: 0.3 W/kg) found no evidence of effects on latency phase, mammary tumor rate, general tumor growth or survival time of the animals.

Toler and colleagues (1997) described similar findings in 200 female C3H/HeJ mice held for 21 months (22 hours per day, 7 days per week) in a pulsed EMF (435 MHz, SAR: 0.32 W/kg) being compared to 200 sham-exposed animals. There was no difference between survival rates of the mice; concerning endpoints (mammary tumors, tumor latency time, incidence and growth rate) no group differences were detected. The tumor rate of all non-target organs/tissues also showed no differences concerning incidence caused by field exposure.

Experimental studies on a possible carcinogenous promotion/co-carcinogenesis caused by HF-EMF exposure

Szmigielski, Szudzinski and colleagues very early examined the impact of electromagnetic field exposure (2450 MHz) on the initiation of tumors in laboratory mice (Szmigielski et al. 1982, Szudzinski et al. 1982). C3H/HeA mice with a high spontaneous mammary tumor rate and Balb/c mice developing skin tumors after application of benzopyrene (skin treatment) were EMF exposed for several months for 2 hours per day/6 days per week showing an increased tumor development (earlier incidence) and an increased metastasis of skin tumors in Balb/c mice, as well as very early occurring mammary tumors in the C3H mice; in both early studies, thermal effects (SAR: 2-8 W/kg) can not be excluded.

Tests on the promoting effect of a 3-weeks exposure (7 hours per day, 5 days

per week) at cw (915 MHz, SAR: 1.7 W/kg) and different pulsed (915 MHz, SAR: 0.008 to 0.4 W/kg) fields were conducted by Salford et al. (1993) in a rat glioma test model. Here, tumor genesis after inoculation of the neoplasm RG2 cell line in male and female Fischer rats of the exposed groups (n=37) was compared to non-exposed control animals (n=37). As soon as neurological symptoms occurred, the animals (EMF exposed, each with a corresponding control animal) were sacrificed and examined histologically. Differences concerning tumor development (survival time, tumor size, tumor rate) between the two treatment groups could not be detected.

Higashikubo et al. (1999) examined the influence of electromagnetic field exposure at 835.62 MHz (FMCW signal) or 847.74 MHz (CDMA signal) with average SAR values of $0.75 + 0.25$ W/kg on CNS tumors in the brain of Fischer rats. The animals were intracranially inoculated with 2-200 cells of a 9L gliosarkoma culture. They were exposed for up to 150 days after tumor cell transplantation for 4 hours per day and for 5 days per week. The animals' mortality was significantly dependent on the number of inoculated tumor cells, whereas FMCW or CDMA exposure had no additional effects on the rats' survival rate. Further, the brain weight of the animals was measured; there were no alterations either in tumor-bearing or 'healthy' animals (inoculated with tumor cells or sham-treated) after EMF treatment.

Imaida and colleagues (1998) examined the possible promoting effect of pulsed HF exposure on chemically induced liver tumors. Male Fischer rats were exposed for six weeks under near-field conditions of the in Japan used PDC mobile radio net (929.2 MHz, 90 minutes per day, 5 days per week) based on TDMA (Time Division Multiple Access) to maximum SAR values of 7.2 W/kg (whole body) and/or local peaks of 2.0 W/kg (liver tissue) after initiation with DEN (200 mag/kg body weight,

ip.) and partial hepatectomy. The average whole body SAR amounted to 0.8 W/kg with temporally limited SAR peaks of 2.4 W/kg. Number and size of glutathione-s-transferase (GST) positive areas (foci) in the liver seen as pre-neoplasm alterations were compared in all animals after 8 weeks. Under these test conditions no significant differences between exposed and sham-exposed rat livers were detected.

In a 2-years study Adey and colleagues (1999) investigated the impact of field exposure to North American mobile phone nets (836.55 MHz modulated, TDMA) on spontaneous or transplacentally ENU-induced brain tumors in the offspring of F344 rats. The animals were EMF exposed (far-field) from day 19 of gestation (in utero) until day 21 and again from day 35 for 22 months. The specific absorption rates occurring in the near-field were identified by the authors as amounting to 1.8 W/kg (females, average body weight 236 g) and/or 2.3 W/kg (males, average body weight 462 g). At no time during the course of the study more brain tumors were detected in the exposed experimental animal groups than in comparable controls meaning that under comparable mortality conditions there was no evidence of (brain tumor) initiating and/or promoting effects of EMF exposure either in the non-treated group or in the ENU initiated offspring.

In 1997 Repacholi and co-authors published sensational results of a long-term study (18 months) on 201 mice showing a significantly increased lymphoma rate after daily exposure to a EMF with GSM features (Repacholi et al. 1997). 101 offspring of transgenic Ei-Pim 1 females developing up to 10% increased spontaneous lymphoma rates during the first 10 months after birth, as well as (non-transgenic) C57BL males during this 18-months study were whole body exposed for 60 minutes per day (2 x 30 min) to a 217 Hz pulsed 900 MHz field, at a field strength of 2.6-13 W/m², whereas 100 animals of the control group were sham-

treated. The authors identified a specific absorption rate in mouse phantoms of 3 different weight classes as ranging from 0.008-4.2 W/kg to average 0.13-1.4 W/kg. During the 18-months experiment a macropathological test was carried out in all died and sacrificed mice. 22 animals of the control group and 43 animals of the treatment group showed lymphoma, in other words, the authors detected a significant rise ($p < 0.001$) of the lymphoma rate (22% versus 43%) caused by field exposure.

As not all 201 mice of this study were examined histologically, it was not possible to trace back the tumor rate to the initial 100/101 animals (mentioned percentages therefore are not realistic). At the end of the 18-months study the clinically healthy mice were considered as survivors and sacrificed without further examination. This proceeding is to be criticised, since (still) clinically healthy unobtrusive mice but carrying a lymphoma could have been missed. Lymphoma diagnosis made during section based upon exterior examination or macroscopic findings (not carried out) is questionable. Further, the exact number of survivors is missing thus preventing detection of the number of lymphoma animals among histologically examined mice. In addition, 14 of the died animals (7/7) according to the authors were too autolytic to carry out histopathological examinations (this can falsify results, too). The number of autolytic and thus not evaluated mice is very large if compared to standardised GLP examinations. Each routine carcinogenesis study should be repeated if more than 10% of the animals are not fully examined.

The significance of the use of transgenic $\text{E}\mu$ Pim 1 mice and/or offspring of transgenic and non-transgenic mice ($\text{E}\mu$ Pim 1 x C57BL/6Ntac) in this study remains questionable: Nowadays, transgenic mice are used rather for short-time tests with the purpose to confirm results of long-term tests or to replace rather ex-

pensive long-term tests. At a test duration of 18 months the advantages of using transgenic laboratory animals (high cost) are highly dubious and/or the use of hybrid animals born after interbreeding of C57BL mice even proves disadvantageous since comparable data (so-called history data such as average life duration, spontaneous tumor rate etc.) of these animals for evaluation, discussion and/or classification of the study are lacking. Last, the authors also offer no explanation of the extremely short daily EMF exposure (2 x 30 minutes); here, a longer daily whole body field exposure of transgenic $\text{E}\mu$ Pim 1 mice 2 within a 10-months or a 24-months experiment in nowadays often used and acknowledged mice stems (f.e. B6C3F1, CD1, CBA) according to NTP/IARC standard would make more sense. All in all, the experimental design and/or particularly the conduction and evaluation of this study are not suited for health risk assessment in humans caused by chronic EMF exposure.

Experimental studies on possible carcinogenous progression caused by HF-EMF exposure

At present, studies on tumor progression are still rare. An increased mortality rate, and increased rates of metastasing tumors found in chronic studies could be useful as a prove for progressive neoplasm effect (process).

EMF studies on tumor progression were performed by Santini and colleagues (1988) in C57B1 mice after subcutaneous application of melanoma cells. The uniform (cw) or pulsed field exposure (2.5 hours per day; 6 days per week, maximum 46 weeks) of the animals (2450 MHz, SAR: 1.2 W/kg) produced no statistically significant differences concerning tumor development between both treatment groups and the non-exposed control group after analysing the endpoints of tumor size and survival duration.

Studies on possible carcinogenesis caused by NF-EMF exposure

As numerous experimental studies already have been carried out concerning the area of low-frequency EMF exposure (EL-EMF) in different test systems and/or on different carcinogenes dealing with tumor promoting effects, a review of these (statistically verified) positive promotion studies applying a GSM characteristic field exposure seem adequate to answer the question of possible health risks of high-frequency field exposure.

Beniashvili et al. (1991), for example, report a shortened latency period concerning tumor occurrence, a significantly increasing mammary tumor rate (adenocarcinomas) and an increased occurrence of malign neoplasms in rats after MNU (methyl nitrosourea initiation) and a 2-year field exposure of 3 hours per day (50 Hz, 20 μT).

Löscher and co-workers published a series of experiments on the promotion of mammary tumors caused by ELF-EMF. Female Sprague-Dawley rats were intragastrally given 7.12 dimethyl benzo[a] anthracene (DMBA) via pharynx tube (initiation). Subsequently, the animals were field exposed for 24 hours daily for several weeks (50 Hz; 50 μT and/or 100 μT). A statistically significant increase of mammary tumors initiated by DMBA was detected by means of palpation (Löscher et al. 1993); during the following examinations in the EMF treatment group a macroscopically significant increase of larger sized knots were indicated (50 Hz, 100 μT) (Baum et al. 1995, Mevissen et al. 1996). Histological examinations revealed similar tumor incidence in the treatment group and the control group; in the field exposed group, however, significantly more often malign tumors of the suction apparatus were diagnosed (Baum et al. 1995). Recently, there even are reports that claim a significantly increased mammary tumor rate

caused by field exposure (Thun-Battersby et al. 1999).

The live focus assay is a further possibility of a sensitive study on substances with promoting effects. Here, after a partial hepatectomy and application of subcarcinogenous doses of for example diethyl nitrosamine (DEN) often phenotypically altered pre-neoplasm herds (foci) or liver tumors (number, volume part, marrow enzymes etc.) found in analysis that only occur after subsequent treatment with promotion agents. The promoting effect of a large number of naturally occurring or synthetic substances (hormones, chlorated hydrocarbon, medicines [phenobarbital]), but also of gamma radiation was tested by means of the liver focus assay proving them to be positively promoting. Also the fact that low-frequency field exposure studies were performed using the liver foci test proceedings (Rannung et al. 1993) also increases the relevance of tests on possible promoting effects of HF-EMF.

Promotion tests in the mouse skin, the classic multi-phase model test of carcinogenesis concerning possible effects of low-frequency electromagnetic fields after tumor induction via DMBA have been repeatedly performed achieving different results. Only Rannung et al. (1994) found statistically noticeable differences, i.e. significantly different tumor rates between continually exposed and intermittently field exposed SENCAR mouse groups, and detected a dose-rationally (flux density, hours of field exposure) significant increase in number of neoplasms per tumor-bearing mouse. Tumor incidence compared to the control group was not altered; thus, this model does seem less adequate for HF-EMF exposure.

As epidemiological studies already very early drew a connection between neoplasm alterations (f.e. brain tumors) in children and electromagnetic field exposure in the domestic environment (Wertheimer and Leeper 1979) and this assumption as yet could not be disproven, the experimental

testing also at high-frequency electromagnetic field exposure with GSM signals seems to be useful. In this context, studies on NF-EMF promotion in ethyl nitrosourea (ENU) induced neurogenic neoplasms in Fischer rats are of interest (Mandeville et al. 2000). Mandeville and colleagues under standardised NTP/NIEHS conditions (U.S. National Toxicology Program/National Institute of Environmental Health Sciences, USA) exposed the offspring of female F344 rats in utero using 5mg/kg ENU (iv) or sodium chloride as a control (day 18 of gestation); 48 hours later they were field exposed to < 0.02 μ T (sham-treatment group) or to 2, 20, 200 and 2000 μ T for 20 hours per day until birth. At the end of this 65-weeks study no significant influence on the neurogenic tumor rate or on survival duration of the offspring caused by field exposure was identified (see also Adey et al. 1999).

Studies on possible effects of functional parameters caused by HF-EMF exposure

In addition to the investigation of morphologically detectable alterations, studies on possible modifications of functional parameters seem to make sense and be sufficiently sensitive to indicate possible changes.

Potential effects on behavior caused by EMF exposure

Very early behavioral tests (open field test, studies on locomotor activity, learning tests) required for the investigation of potential health risks caused by electromagnetic field exposure were performed in EMF exposed laboratory animals. Potential noticeable behavioral parameters during or immediately after exposure should provide evidence of a functional impairment of neuronal performance caused by field exposure.

Galvin and colleagues (1986) exposed rats (2450 MHz, 10 mW/cm², 3 hours per day) on day 5 through 20 of gestation

(prenatally) or on day 2 through 20 post partum, subsequently subjected these animals on day 10 and 100 and/or on day 30 through 36 after birth to a great number of behavioral experiments (different stimuli). On day 30 and/or day 30 through 36 after birth exposed rats (until day 20) showed a greater body weight and less stamina during the swim test compared to sham-exposed control animals. This was interpreted by the authors as an effect of electromagnetic exposure.

DeWitt and colleagues exposed rats for 90 days (7 hours per day, cw, 2450 MHz, 0.5 mW/cm², SAR: 0.14 W/kg) and examined the animals every 30 days applying numerous behavioral tests (pain sensitivity, active avoidance learning, operant learning). Since only learning tests showed differences, the authors concluded that field exposure should lie below the limit value of behavioral impact.

Mitchell and colleagues (1988) exposed rats (cw, 2450 MHz, 10 mW/cm²) for 7 hours and performed extensive behavioral tests in the animals immediately after the high-frequency field exposure. The EMF exposed animals showed a significantly decreased locomotor activity and decreased stimuli response compared to sham-exposed rats.

Though Trzeciak et al. (1993) did not detect alterations of locomotor activity or behavioral alterations in exposed rats during the open field test, the animals of both field exposure groups after 20-days exposure showed a decreased excitability (2 hours per day; static, 0.49 T or 50 Hz ELF-EMF, 0.018 T).

After acute NF exposure (60 Hz, 1 mT, 1 hour) of rats in the water-maze (water-maze test) Lai and colleagues (1998) could not detect any significant differences in learning behavior concerning localisation of the swimming platform, though here, too, the exposed animals showed a decreased activity and different swimming behavior (spatial orientation); the authors assumed effects of field exposure.

The same test approach of 2450 MHz HF exposure (2 μ s pulse width, 500 pulses/s, 2 mW/cm², 1.2 W/kg SAR, 1 hour), however, showed a learning impact during the water-maze test of the exposed animals compared to the non-treated control group (Wang and Lao 2000).

Possible effects of EMF exposure on ornithine decarboxylase and calcium

Further, some in vitro EMF studies detected functional alterations (ornithine decarboxylase, ODC, calcium) of the isolated culture cells; apart from providing concrete test results, the studies also were meant to prove that there is no impact of electromagnetic field exposure on cells whatsoever (Byus et al. 1987; Blackman et al. 1985, 1988, Dutta et al. 1989).

Hibshoosh et al. (1991) also found evidence of the effect of high ODC values on cell transformation; and recently, Mullins et al. (1999) confirmed that field strength depends on this ODC increase in the cell culture, whereas the significance of calcium value alterations (stimulus conduction/immune system) for example concerning carcinogenesis remains unclear.

While Smialowicz et al. (1982) discovered no alterations of the mitogen-stimulated immune response at uniform or pulsed RF exposure (425 MHz) compared to non-exposed BALB/C mice, Lyle et al. (1983) observed a restriction of cytotoxicity in T-lymphocytes after exposure to an amplitude modulated RF field (450 MHz, 60 Hz); unmodulated fields of the same frequency did not show this effect.

Also an unpulsed high-frequency field exposure (20 MHz, SAR: 0.3 W/kg, 6 hours per day, 5 days per week) of Sprague-Dawley rats over a period of 6 weeks did not lead to any effect on the examined haematological and/or clinical/chemical parameters (Wong et al. 1985).

In contrast, Liburdy and Wyant (1984) demonstrated the impact on binding capacity of human immunoglobulins (IgM, IgA, IgG) and on mouse B-lymphocytes of

RF field exposure (10 MHz, SAR: 0.134 W/kg) also below the legally set SAR limit of 0.4 W/kg; further, Lyle and co-authors (1991) assumed after tests in cultivated mouse lymphocytes showing an altered calcium absorption at pulsed low-frequency field exposure concluded that electromagnetic exposure has an effect on calcium-dependent immune functions of lymphocytes.

However, all in all the relevance of these in vitro OCD/CA results is not sufficiently verified; the assumption that such cellular changes possibly are indicators of illnesses (of the whole organism) is not undisputed. Therefore, purported molecular biological EMF effects should be verified and eventually corresponding models should be developed for use in animal experiments. In this context, the examination of enzymatic/hormonal and clinical/chemical parameters in newer animal experimental studies seems to make sense.

Today, the significance of such in vitro results for assessing human health hazards is still seen as controversial; to this reason, in vivo exposure studies are carried out.

Since also study results from of behavioral testing following to electromagnetic exposure still have huge deficits and uncertainties, they should always be accompanied by such relatively economical tests in long-term experiments (possibly as a satellite group).

Resumen

At present, it is impossible to scientifically prove the absence of long-term effects of athermal HF-EMF exposures (and GSM); however, the available studies do not give convincing evidence of a health risk for humans, either.

Besides the small number of experimental EMF studies, also the use of uncertain exposure parameters (uncertain non-/athermal field exposure conditions), particularly in 'older' experiments, should be mentioned as one reason for this problem.

However, as soon as currently performed HF-EMF studies will be concluded and further planned experimental studies will be realised, higher safety will be achieved concerning the evaluation of possibly existing health risks at field exposure to high-frequency mobile radio signals.

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