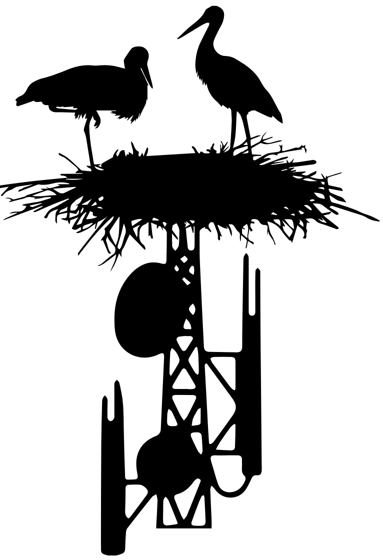
04/2024

ElektrosmogReport

Technical information on the significance of electromagnetic fields for the environment and health.



Base stations and birds

Is there an effect of electromagnetic waves from base stations on the breeding success of Ciconia ciconia in Algeria?

Sakraoui D, Ziane N, Ghalem R, Boukheroufa M, Habbachi W. Is there an effect of electromagnetic waves from base stations on the breeding success of Ciconia ciconia in Algeria? Biosystems Diversity. 2023 Nov 7;31(4):493-9. https://doi.org/10.15421/012358

Numerous laboratory studies have shown the harmful effects of radiofrequency waves on physiological processes in humans and on animal health. These studies have mostly been conducted in the laboratory, where all parameters can be controlled, but field work is more complex and involves methodological and technical difficulties. Experiments to study the effects of electromagnetic radiation on living organisms are complex because of the large number of variables that need to be controlled. The complexity of this control makes it difficult to achieve the „identical conditions" required for replication. Birds have been used extensively to analyze the environmental significance of exposure to non-ionizing radiation. Their ability to detect magnetic stimuli has been widely documented. In Algeria, the white stork Ciconia ciconia nests frequently in the Mediterranean region. Storks seem to be an interesting species to study the potential effects of electromagnetic waves from base stations. In the study region,

„Stork nests situated directly on the antennas experience very low rates of reproductive success."

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Editorial team ElektrosmogReport:

Dipl.-Biol. Isabel Wilke (IW), Roman Heeren (RH), M.Sc., Alain Thill (AT), M.Sc. | Contact: report@emfdata.org

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About us:

The ElektrosmogReport has been published since 1995 and is issued by diagnose:funk since 2019. diagnose:funk is an independent environmental and consumer organization that has been campaigning for protection from electromagnetic fields since 2009. For this purpose, diagnose:funk explains the harmful effects of mobile phone and Wi-Fi radiation and calls for sustainable technical solutions for health-friendly telecommunications. Our motto: Use technology sensibly!

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they are the only species besides house sparrows that build their nests directly on base stations and spend a lot of time in the nest. The scientists' aim was to determine whether there is a correlation between exposure to electromagnetic waves emitted by mobile phone base stations and the reproduction rate of white storks.

Study design and implementation:

The field observations took place over two consecutive years, 2020 and 2021. The scientists observed the species' eggs and chicks twice a week with binoculars. The stork nests in three districts of Algeria (Ben M'hidi, Dréan, Berrahal) were counted to estimate the white stork population in each location. The observations began with the arrival of the storks and covered the period of nest building and care, as well as the period from egg laying to fledging.

The protocol used to categorize the stork population is a repetition of an earlier study by Balmori (2005), except that here the scientists used three groups (0 m, less than 200 m, more than 300 m) instead of two (-200 m, +300 m).

A total of 140 nests were selected and divided into three groups: G1 consists of nests that are 0 m away from the base stations, i.e. located on the base station (27 nests). G2 consists of nests that are less than 200 m away from the base stations (43 nests). G3 consists of nests that are at least 300 m away from a base station (70 nests).

Results:

Number of nestlings: The number of young storks in the nest varied between 0 and 4 per nest at the three sites. Nests without fledglings were located exclusively on the base stations (G1), while nests with 4 fledglings were most frequently found in nests more than 300 meters away from the antennas.

Effects of base stations on breeding success:

In 2020, group G1 (27 nests directly at the base stations) had an average of 0.592 young per nest, with a percentage of 51.9 % of nests without young. Group G2 (43 nests at a distance of less than 200 m from the antennas) had an average of 2.046 young per nest and no nests without young. Group G3 (70 nests at a distance of more than 300 m from the antennas) had an average of 2.8 young per nest and no nests without young.

In 2021, the trends remain similar. Group G1 had an average of 0.814 young per nest, with a percentage of 40.7 % of nests without young. Group G2 had an average of 2.186 young per nest, with no nest without young. Group G3 had an average of 2.87 young per nest and no nests without young.

The results of the paired T-test show no significant difference ($P = 0.162$) between the years 2020 and 2021. With regard to the average number of young per nest, the analysis of variance (ANOVA) showed a highly significant difference between the three groups ($F = 122.21$, $p < 0.001$) for the years 2020 and 2021.

Linear regression analysis between the distance from base stations and the average number of young per nest shows a very highly significant relationship ($p < 0.0001$).

Conclusions:

These results indicate that the proximity of nests to mobile phone base stations influences the reproduction of storks. Nests that are located directly adjacent to the antennas have a very low reproductive success. The further away the nests are from the antennas, the greater the reproductive success, with nests more than 300 m away from the antennas having the highest reproductive success.

These results are consistent with those of Balmori (2005), who studied 60 white stork nests. According to Balmori, 40 % of the 30 nests less than 200 m from a mobile phone base station did not yield any chicks, while in another colony with 30 nests more than 300 m away, only 3.3 % failed to produce to chicks. (AT)

Base stations and bees

Oxidative stress response of honey bee colonies (Apis mellifera L.) during long-term exposure to a frequency of 900 MHz under field conditions

Vilić M, Žura Žaja I, Tkalec M, Tucak P, Malarić K, Popara N, Žura N, Pašić S, Gajger IT. Oxidative Stress Response of Honey Bee Colonies (Apis mellifera L.) during Long-Term Exposure at a Frequency of 900 MHz under Field Conditions. Insects. 2024 May 20;15(5):372. https://doi.org/10.3390/insects15050372

In concert with the widespread use of cell phones and other sources that generate radiofrequency electromagnetic fields (RF-EMF), there is growing public concern about harmful effects on human and animal health. In fact, the results of numerous studies have shown that exposure to RF-EMF (cell phones, routers, base stations) has various non-thermal biological effects such as oxidative stress, immune system dysfunction, genotoxic effects as well as effects on reproduction and fertility. These biological effects have been demonstrated *in vitro* and *in vivo* in various animal species, including mammals and insects. The honeybee is one of the most important insects for maintaining balance in natural ecosystems. The honeybee is thought to play the most important role in pollination of all insect species in the Hymenoptera order, as it is involved in almost 80-85 % of pollination of the world's crops. Previous studies on the effects of RF-EMF on honey bee colonies have mostly examined adult honey bees in the laboratory or under unnatural conditions. To date, there are many uncertainties about the effects of RF-EMF on honey bee colonies due to the lack of studies under field conditions. The aim of this study was to answer the following questions: (a) Could RF-EMF cause lipid peroxidation and changes in three vital antioxidant enzymes at different stages of honey bee development under field conditions? (b) Is there a possibility of a chronic effect on oxidative stress after one year of exposure?

Study design and implementation:

The study was conducted on honey bees exposed to RF-EMFs from mobile phone base stations in their natural environment. A total of fifteen (15) honeybee colonies were randomly selected. The experiment was conducted at three different locations:

Five honey bee colonies were located near mobile phone base stations with a frequency of 900 MHz and an average electric field of 1000 mV/m or 2.65 mW/m², referred to as high intensity (HI) (67 and 160 m from two base stations, respectively). Five other honey bee colonies were located at a site with an average electric field of 30 mV/m or 0.002 mW/m², named low intensity (LI), about 800 m from the base stations. Five honeybee colonies were located at a site with a field strength of 70 mV/m or 0.013 mW/m², named medium intensity (MI), at a distance of about 1600 m from the base stations.

All colonies were exposed for one year and samples were taken three times (2 weeks, 5 months and 1 year) after the start of the monitoring. Five- to six-day-old larvae, pupae in the violet eye stage and the midgut of adult honey bees (forager bees) were collected from each colony.

The activity of glutathione S-transferase (GST), catalase (CAT) and superoxide dismutase (SOD) as well as the degree of lipid peroxidation (TBARS) were determined in accordance with a previously published study by the same authors.

Results:

When comparing the results of the same observation period, the GST activities in all honeybee samples at locations with different electric field strengths (30, 70 and 1000 mV/m) did not differ statistically significantly.

CAT activity in the larvae was statistically increased ($p < 0.05$) at the HI site (1000 mV/m) compared to the MI and LI sites with lower electric fields in the fifth month of exposure, while it was increased at the LI site (30 mV/m) compared to the MI (70 mV/m) and HI sites (1000 mV/m) after one year of exposure. CAT activity in the midgut of the adult honey bee colony was significantly higher ($p < 0.05$) at the HI site (1000 mV/m) compared to the MI site (70 mV/m) after the two-week exposure as well as after the one-year exposure. On the other hand, it decreased at the HI site (1000 mV/m) compared to the LI site (30 mV/m) after the 5-month exposure.

The SOD activities in all honey bee samples (larvae, pupae and midgut) did not differ significantly when the results were compared between the different sites over the same observation period.

In the larvae, the TBARS concentration (= lipid peroxidation) was significantly higher at the HI site (1000 mV/m) compared to the other two sites, MI (70 mV/m) and LI (30 mV/m), after the two-week exposure, while after the one-year exposure, TBARS were also higher at both the HI and LI sites compared to MI (70 mV/m). The TBARS in larvae of honey bees from the LI site were significantly increased after one year of exposure compared to after two weeks of exposure.

Conclusions:

The authors of this study had previously reported that GSM 900 MHz radiation affects the antioxidant system of honey bee larvae after short-term exposure under laboratory conditions. The results obtained in this study are consistent with the previous study. Thus, the activity of antioxidant enzymes and the concentration of lipid peroxidation products depend on the developmental stage of honeybees, the ambient electric field strengths and the duration of exposure. The overproduction of reactive oxygen species (ROS) after exposure to GSM RF-EMFs is scavenged by SOD, CAT and GST, the main antioxidant enzymes in honey bees.

One of the reasons for the observed antioxidant enzyme activity at certain developmental stages could be the physiological developmental profile of these enzymes and their function in honey bees. Indeed, it is known that the activities of SOD, CAT and GST in a larva increase slightly from the first to the sixth day and then decrease until the end of honeybee development, with CAT activity decreasing the most. Based on the results that TBARS levels (at two-week and one-year exposure) and CAT (at five-month and one-year exposure) were significantly increased in larvae, the authors hypothesize that larvae are more sensitive to RF-EMF exposure than pupae. The higher TBARS content could be explained by the lipid content of the larvae, which have a significantly higher fat content than the pupae and are therefore more sensitive to oxidative stress. In contrast, no statistical differences were found in the developmental stage of the pupae between different sites at all three sampling times. One possible reason for this is the fact that the pupal stage is able to overcome the potential cell damage caused by oxidative stress due to the higher physiological activity of the antioxidative enzymes. CAT, SOD and GST activity did not show linearity with respect to field strength and time of sampling. As the mechanisms of RF-EMF are not yet well understood, it is difficult to say what effects such radiation might have on the physiological characteristics of bees. (AT)

Nutritional supplementation may protect against RF-EMF effects

Exploring edible bird nest's potential in mitigating Wi-Fi's impact on male reproductive health

Maluin SM, Jaffar FHF, Osman K, Zulkefli AF, Mat Ros MF, Ibrahim SF (2024): Exploring edible bird nest's potential in mitigating Wi-Fi's impact on male reproductive health. Reproductive Medicine and Biology, 23(1), 1–13. https://doi.org/10.1002/rmb2.12606

Edible bird's nest (EBN) possesses a range of health-promoting properties, such as hormonal, antioxidative, and cell proliferative effects. The potential of EBN to mitigate adverse effects of mobile phone radiation and Wi-Fi has attracted public and scientific interest in the context of globally increasing male infertility. Both thermal and biological effects of non-ionizing radiation on humans have been documented. The highly complex regulation of spermatogenesis involves the interaction of various male reproductive hormones, including gonadotropin-releasing hormone (GnRH), follicle-stimulating hormone (FSH), luteinizing hormone (LH), testosterone, and estrogen. However, studies have shown that the delicate balance of this process can be disrupted by mobile phone radiation. This disruption is associated with reduced testosterone levels, impaired spermatogonia proliferation, increased sperm DNA damage, and decreased sperm quality. This study evaluated the effects of Wi-Fi exposure on male reproductive hormones, spermatogenic proliferation, and sperm quality in rats. Additionally, the potentially protective effect of EBN as a dietary supplement was investigated.

Study design and implementation:

A total of 36 male Sprague-Dawley rats were divided into 6 experimental groups (n = 6): unexposed control, unexposed EBN, unexposed E2 (17ß-estradiol), Wi-Fi, Wi-Fi EBN, Wi-Fi E2. For Wi-Fi exposure, a commercial router operating at 2,45 GHz was utilized. It was positioned approximately 20 cm from the rat cages and maintained constant communication with a Raspberry Pi via a ping protocol. The exposure period lasted 8 weeks. The weight of the testes, epididymis, and seminal vesicles was assessed as an organ coefficient (weight ratio of experimental group/control). Sperm parameters (count, motility, and viability) were determined. Furthermore, serum levels of reproductive hormones FSH, LH, testosterone, and estradiol were analyzed. As a final step, the researchers examined the expression of estrogen receptors (ER) and markers of spermatogenic proliferation on protein and mRNA basis.

Results:

Wi-Fi exposure did not result in significant changes in organ coefficients. However, E2 administration led to a significant reduction in the organ coefficient of the seminal vesicles. Wi-Fi exposure caused significant deterioration in sperm parameters, which were restored by EBN supplementation in case of sperm concentration. Regarding reproductive hormones, Wi-Fi exposure resulted in a significant decrease in FSH and testosterone levels, while LH and E2 showed no significant changes. EBN supplementation mitigated the Wi-Fi effects, restoring reduced FSH and testosterone levels and significantly increasing LH and E2 levels. Estrogen receptor mRNA expression was altered following exposure: ERα was significantly reduced, while ERß was significantly increased. However, these changes were not reflected in protein expression. A similar trend was observed, but it did not reach statistical significance.

Conclusions:

The authors of the presented publication conclude from their findings that Wi-Fi impairs male reproductive hormone production in the hypothalamic-pituitary-gonadal axis and testicular function during spermatogenesis. Consequently, Wi-Fi reduces sperm quality and contributes to male infertility. They hypothesize that the testosterone and ERα level decrease may be linked to Leydig cell damage. The increase in ERß could be associated with a Wi-Fi-induced shift in the sperm cell cycle. Supplementation with edible bird nest appears to mitigate the damaging effects of Wi-Fi. Sperm parameters, testosterone levels, and gonadotropin levels were significantly increased in treated animals. This may be due to an influence on estrogenic activity (increased T/E2 ratio) as well as antioxidative and anti-inflammatory properties of EBN. (RH)

Antioxidant protects male reproductive organs

The histological and biochemical analysis of the effects of radiofrequency radiation on testis tissue of rats and the protective effect of melatonin

Yardim A, Sirav B, Tomruk A, Oruç S, Delen K, Kuzay D, Seymen CM, Take Kaplanoğlu G (2024): The histological and biochemical analysis of the effects of radiofrequency radiation on testis tissue of rats and the protective effect of melatonin. Turkish Journal of Medical Sciences, 54(4), 858–865. https://doi.org/10.55730/1300-0144.5857

Increasing health issues in humans have raised questions about a possible link to mobile phone radiation. The interaction of radiofrequency radiation may include structural changes in biomolecules and disruptions of regulatory cascades in biochemical processes. A mobile phone-induced depolarization of the mitochondrial membrane can trigger excessive production of reactive oxygen species (ROS) and hydroxyl radicals. A common hypothesis on how mobile phones negatively affect male fertility involves these radicals attacking reproductive tissue. The main effects of exogenous melatonin treatment are likely to be on the electron transport chain as an antioxidant. Detoxification of excess radicals through increased activity of antioxidant protective mechanisms may have significant benefits for the reproductive system. The present study investigates the impact of GSM-like 2600 MHz radiofrequency irradiation on the male reproductive system and the potential protective role of melatonin using a rat model.

Study design and implementation:

Male Wistar albino rats were divided into six groups (n = 6):

i. unexposed control;
ii. sham-exposed control;
iii. high-frequency exposed;
iv. unexposed + melatonin;
v. sham-exposed + melatonin;
vi. high-frequency exposed + melatonin.

The electric field strength within the exposure apparatus was 21.74 V/m, resulting in a whole-body SAR of 0.616 W/kg (1 g average) and 0.297 W/kg (10 g average). Exposure was conducted at 2600 MHz for a period of 4 weeks, 5 days per week, 30 minutes per day. The researchers examined histological changes in testicular tissue as well as oxidative and antioxidative biochemical parameters (malondialdehyde, nitric oxide, glutathione, and glutathione peroxidase).

Results:

The overall histological structure of the testes was identical in the sham and unexposed groups, both with and without melatonin administration. However, it was observed that the melatonin-treated groups displayed increased spermatocytes in some seminiferous tubules and higher sperm density in the lumen. GSM-like exposure did not cause structural disruptions in the seminiferous tubules. However, severe edema was observed in the germinal epithelium of the seminiferous tubules, accompanied by structural and functional disruption of the epithelium. Tubular connections between cells were interrupted. Prominent vacuolization was observed in the interstitium. Furthermore, spermatogenic cell populations and connective tissue elements were reduced compared to the control groups. Melatonin administration improved the radiofrequency-radiation-induced damage, although edema and disrupted intercellular connections were still observed. Compared to the exposed group without melatonin, regeneration of spermatogenic cell populations in the interstitium was observed. Oxidative stress parameters mirrored the histological findings. Compared to the controls, the exposed group (iii) showed significantly increased lipid peroxidation and nitric oxide concentrations. Simultaneously, glutathione and glutathione peroxidase levels were significantly reduced. Melatonin treatment led to a significant improvement in oxidative stress parameters in the exposed animals.

Conclusions:

This study examined the effects of GSM-like radiofrequency irradiation on rat testicular tissue and the potential protective role of the antioxidant melatonin. The results, from both histological and biochemical analyses, indicate a harmful effect of mobile phone exposure on male reproduction. Administration of exogenous melatonin may to reduce these adverse effects. Furthermore, the data suggest that melatonin increases sperm production, raising the question whether its stimulatory and/or antioxidant effects contribute to mitigating the effects of radiofrequency irradiation. The authors note that further studies are needed, particularly quantitative histological analyses of testicular tissue. (RH)

Mobile phone effects on the Brain

Exposure to radiofrequency induces synaptic dysfunction in cortical neurons causing learning and memory alteration in early postnatal mice

Kim JH, Seok JY, Kim YH, Kim HJ, Lee JK, Kim HR (2024): Exposure to Radiofrequency Induces Synaptic Dysfunction in Cortical Neurons Causing Learning and Memory Alteration in Early Postnatal Mice. International Journal of Molecular Sciences, 25(16). https://doi.org/10.3390/ijms25168589

As mobile phone use is typically associated with close head proximity, potential effects of mobile phone exposure on the central nervous system (CNS) are of particular concern. Despite scientific controversy, there is accumulating evidence that mobile phone radiation may have harmful effects, such as impairment of intracellular calcium homeostasis, neuronal damage and disruption of neurotransmitters in the CNS. Previous studies have demonstrated that the specific absorption rate (SAR) of five-year-old children is twice that of 20-year-old adults. Therefore, effects of mobile phone emission may be more severe in children, since their CNS is still developing. Of particular relevance is the cerebral cortex, which is involved in various crucial functions, including sensory perception, motor control, higher cognitive processes and complex behaviors. Dysfunction of the cerebral cortex is associated with neurodegenerative diseases such as Alzheimer's disease and, in cases of impaired development in children, with attention-deficit/hyperactivity disorder (ADHD) and autism spectrum disorder (ASD).

This study investigates the influence of mobile phone irradiation on the synaptic development of cortical neurons in mice. The focus was on altered expression of key genes and proteins involved in synapse formation, including neurexin, neuroligin, and cyclin-dependent kinase 5 (CDK5). Behavioral changes in the mice were also studied.

Study design and implementation:

The authors exposed newborn mice to radiofrequency radiation for four weeks, starting on the first day after birth. For the first three weeks, this exposure was conducted in the presence of the mother. The young mice were exposed to continuous 1850 MHz waves without frequency modulation for 5 hours per day. The SAR value was 4 W/kg. This is the maximum allowed exposure level for normal mobile phone users in several countries, based on recommendations from organizations such as CENELEC, ICNIRP, and IEEE. (However, 4 W/kg applies to the extremities, while the maximum values for the head and torso are 1.6 and 2.0 W/kg, respectively. Editor's note.) The researchers used electron microscopy to study neuronal development and synapse formation, focusing on dendritic spines. *In vitro* analyses of cultured primary neurons included the expression of PSD95, a key regulator of synaptic plasticity, and neurite outgrowth. The expression of key components of synapse formation (genes: nlgn2, nlgn3, nrxn1a; proteins: CDK5) was subsequently evaluated. Finally, potential behavioral changes as a consequence of radiofrequency exposure were assessed using the Morris water maze test.

Results:

The authors observed a statistically significant reduction in dendritic spines in the cortical neurons of the exposed mice, particularly mushroom-shaped spines, which are known for their strong synaptic signal transmission. Both dendrite formation (PSD95) as well as neurite length and branching were significantly reduced in cultured cortical neurons. These findings suggest that mobile phone irradiation impairs synaptic structure, density, and neurite outgrowth. The expression of synaptic cell adhesion proteins (nlgn2, nlgn3, nrxn1α), which are crucial for maintaining synapses and neuronal connections, was significantly decreased at the mRNA level in the prefrontal cortex of the exposed mice. Additionally, the protein expression of CDK5, which plays a vital role in various neuronal development processes, including synapse growth and maturation, spine formation, and synaptic plasticity, was significantly reduced. Behavioral tests supported the molecular findings. A significant impairment in spatial learning and memory was observed in the young exposed mice.

Conclusions:

Overall, the results of the present publication suggest that under the selected exposure conditions (continuous 1850 MHz field, 4 W/kg SAR, 5 hours/day, 4 weeks), mobile phone radiation impairs synapse formation and function, reducing the levels of essential synaptic molecules. This ultimately leads to diminished cognitive capacity in newborn mice. Dysregulation of synaptic adhesion molecules is associated with various cognitive diseases, including autism spectrum disorders, schizophrenia, and intellectual disabilities. CDK5 is associated with learning and memory processes. For example, CDK5 deficient mice have significant impairments in spatial learning. The findings highlight the harmful potential of mobile phone radiation during development, particularly regarding neurodevelopmental disorders such as autism spectrum disorder. (RH)

Effect of RF-EMF on Bone Homeostasis

Radiofrequency field inhibits RANKL-induced osteoclast differentiation in RAW264.7 cells via modulating the NF-κB signaling pathway

Ding C, Wang H, Yang C, Hang Y, Zhu S, Cao Y (2024): Radiofrequency field inhibits RANKL-induced osteoclast differentiation in RAW264.7 cells via modulating the NF-κB signaling pathway. Electromagnetic Biology and Medicine. https://doi.org/10.1080/15368378.2024.2401554

Bone is a dynamic organ undergoing constant remodeling, regulated by a delicate balance between osteoblast-mediated formation and osteoclast-mediated resorption. Osteoclasts are unique multinucleated macrophages derived from hematopoietic stem cells that are solely responsible for bone resorption. This delicate homeostasis is critical for healthy bone tissue and is disrupted in conditions such as osteoporosis. The RANK/RANKL signaling pathway is particularly important for bone metabolism, as the interaction of RANKL with RANK initiates the differentiation of precursor cells into osteoclasts. Excessive formation of mature multinucleated osteoclasts is a key event in the progression of osteoporosis. Previous studies have shown that various doses of pulsed electromagnetic fields can reduce bone loss in osteoporotic rats. Based on this, the authors of this publication hypothesized that radiofrequency (RF) might exert energy-dependent effects on osteoclast differentiation. This study therefore examined the effects of RF on RANKL-induced osteoclast differentiation in RAW264.7 cells and investigated underlying molecular mechanisms.

Study design and implementation:

The RAW264.7 mouse macrophage cell line was subjected to three distinct power intensities (0.5 W/m^2 = LRF; 1.5 W/m^2 = MRF; 4.5 W/m^2 = HRF) for 4 hours/day over a five-day period, with the cells being exposed to a 900 MHz radiofrequency electromagnetic field. Sham-exposed cells were used as controls. For the osteoclast differentiation experiment, the cells were treated with RANKL. To assess the role of the pro-inflammatory transcription factor NF-κB in mediating the RF effect, the cell line was treated with an NF-κB inhibitor. As a positive control for RF effects on osteoclast formation, the authors used 17ß-estradiol (E2). They analyzed cell viability, apoptosis, osteoclast markers, and components of the RANK/RANKL as well as NF-κB signaling pathways.

Results:

Neither low-dose (0.5 W/m^2) nor high-dose (4.5 W/m^2) 900 MHz radiofrequency affected the viability of RANKL-induced osteoclasts. However, the medium dose (1.5 W/m^2) showed an inhibitory effect of osteoclast cell division comparable to E2 administration. Conversely, apoptosis and osteoclast marker tests revealed that all three 900 MHz doses were capable of inducing apoptosis during osteoclast differentiation. Thus, radiofrequency radiation exerts significant inhibitory effects on RANKL-induced osteoclast differentiation, with the most pronounced inhibition observed at the medium RF dose. Analysis of RANKL signaling pathway components RANK and TRCAP revealed a significant decrease in mRNA and protein levels following exposure to 1.5 W/m^2. This suggests that RF may impair the capacity for differentiation by inhibiting the formation of differentiation markers. Finally, the effect of 900 MHz exposure at 1.5 W/m^2 on NF-κB was investigated. RF exposure impaired the translocation of NF-κB into the nucleus, which in turn inhibited the NF-κB-regulated transcription factor NFATc1. These findings indicate that RF might impair genes associated with osteoclast differentiation via the NF-κB signaling pathway and NFATc1.

Conclusions:

The researchers concluded that 900 MHz RF exposure at a power density of 1.5 W/m^2 can inhibit the differentiation of RAW264.7 cells into osteoclasts. On a molecular level, this inhibition appears to be caused by the prevention of NF-κB translocation into the nucleus, which subsequently impairs differentiation markers. This finding suggests that RF might offer a potential non-invasive approach to effective osteoporosis treatment. (The results of this study indicate that 900 MHz exposure at moderate intensity can significantly affect the differentiation of hematopoietic stem cells. While the authors focused on the therapeutic potential, they also highlight the biological effects of sub-thermal RF exposure on differentiation processes *in vitro*. It is noteworthy that, the authors mention a „window effect" in their publication, which follows a non-linear dose-response relationship where specific RF intensities produce more significant biological effects than lower or higher intensities. These phenomena may help explain the heterogeneity in research findings regarding RF and health and underscore the need for a more comprehensive understanding to assess potential health risks for humans. Editor's note) (RH)

Effect of RF-EMF on a quantum level?

Frequency-dependent antioxidant responses in HT-1080 human fibrosarcoma cells exposed to weak radio frequency fields

Gurhan H, Barnes F (2024): Frequency-Dependent Antioxidant Responses in HT-1080 Human Fibrosarcoma Cells Exposed to Weak Radio Frequency Fields. Antioxidants, 13(10), 1237. https://doi.org/10.3390/antiox13101237

Radiofrequency electromagnetic fields (RF-EMFs) interact with biological systems that contain charged ions and polarized molecules. These interactions can influence cell membranes, transmembrane potentials, and cell cycles. Recent studies in quantum biology have expanded this concept, suggesting that weak magnetic fields, including those induced by radiofrequency, can modulate biological processes on a quantum level. This modulation occurs particularly through mechanisms involving spin states and radical pair mechanisms. These quantum effects may play a significant role in how RF-EMF influences cellular processes, especially the production of reactive oxygen species (ROS). The electron transport chain (ETC) in mitochondria represents a critical site for ROS production, primarily due to the activity of redox-active molecules exhibiting hyperfine interactions. According to Grissom, magnetic fields can modulate the rate of radical pair recombination in biological systems. This may occur through hyperfine interaction-induced interconversion (e.g., from the singlet ground state to a triplet state) or spin-orbit coupling. Radical pair recombination of redox-active molecules can significantly influence ROS formation and oxidative stress responses within the cell. Radical pairs, intermediates in many chemical reactions, can exist with either antiparallel or parallel spins. RF exposure at the frequency of a hyperfine interaction can increase the time these radical pairs spend in the triplet state, increasing the likelihood of dissociation into free radicals. The authors selected the radiofrequency range of 2-5 MHz for this *in vitro* study, based on known hyperfine resonances of iron-sulfur clusters and other key components of the electron transport chain within mitochondria.

Study design and implementation:

The human fibrosarcoma cell line HT-1080 was exposed in a shielded incubator. All cells, both controls and RF-exposed cells, were subjected to an artificial static magnetic field of 45 µT, equivalent to the Earth's magnetic field in Boulder, Colorado. RF-exposed cells were additionally exposed to 20 nT radiofrequency fields between 2 and 5 MHz. The frequency was increased in 0.5 MHz increments (2.0 MHz, 2.5 MHz, 3.0 MHz, etc.). The exposure experiment lasted 4 days. Oxidative and antioxidant parameters were measured, including superoxide dismutase (SOD), reduced glutathione (GSH), hydrogen peroxide (H_2O_2) activity (peroxidase), superoxide anion levels and cell viability.

Results:

Cellular SOD concentrations were significantly increased with combined SMF+RF exposure compared to SMF alone at all frequencies except 3.0 and 3.5 MHz. The increase in SOD activity was frequency-dependent. Similarly, cellular GSH levels were significantly altered in a frequency-dependent manner: GSH levels were significantly decreased at 2.0 and 2.5 MHz but showed a substantial increase at 4.0 MHz. H_2O_2 concentrations were significantly elevated at 2.0, 4.5, and 5.0 MHz compared to the controls but decreased at 3.5 MHz. Superoxide anion levels were significantly increased at 2.0 and 3.0 MHz but significantly reduced at 4.0 and 4.5 MHz. Cell viability exhibited a near-sinusoidal pattern: it was significantly worse at 2.0 MHz compared to controls, improved at 2.5 and 3.0 MHz, worsened again at 3.5 MHz, and improved at 4.0 and 4.5 MHz. The greatest reduction in viability compared to controls was observed at 3.5 MHz, while the greatest improvement occurred at 4.0 MHz.

Conclusions:

The results demonstrate that radiofrequency in the nT range can significantly modulate the activity of critical antioxidant molecules and oxidative stress markers *in vitro*, in a frequency-dependent manner. At 2.0 and 2.5 MHz, fibrosarcoma cells exhibited significant oxidative stress compared to controls, characterized by increased SOD levels and GSH deficiency. At the same time, a significant increase in mitochondrial superoxide radicals was observed. The authors confirm their hypothesis that hyperfine resonance effects at these frequencies can enhance mitochondrial superoxide anion production, requiring an amplified antioxidant response. In contrast, exposure at 4.0 MHz increased cellular viability, paired with a reduction in mitochondrial superoxide levels. This suggests improved mitochondrial function and optimized balance between ROS production and antioxidant mechanisms. At an applied RF field strength of only 20 nT, this study joins a growing body of evidence suggesting that low-intensity electromagnetic fields exert biological effects through non-thermal mechanisms. (RH)

Wireless energy transfer technology poses risks

External RF-EMF alters cell number and ROS balance possibly via the regulation of NADPH metabolism and apoptosis

Chow S-C, Zhang Y, Ng RWM, Hui S-YR, Solov'yov IA, Lui W-Y (2024): External RF-EMF Alters Cell Number and ROS Balance Possibly via the Regulation of NADPH Metabolism and Apoptosis. Frontiers in Public Health, 12(August), 1–11. https://doi.org/10.3389/fpubh.2024.1425023

The popularity of Qi-standard-certified wireless chargers in consumer electronics and manufacturing industries has drawn significant attention. The AirFuel Alliance, established by a group of companies, aims to expand the use of wireless power transfer (WPT) technology for mid-range applications. The ISM frequency band (industrial, scientific, and medical) could operate at 6.78 MHz and be utilized for mid-range transmission. As current safety regulations only consider the thermal effects of radiofrequency (RF) on tissues, potential non-thermal biological effects remain largely unexplored. In the interest of public health, it is imperative to investigate the biological impacts of RF in this context prior to the implementation of WPT technologies. A 2016 study demonstrated that weak RF fields (10 μT at 7 MHz) could influence cell growth and reactive oxygen species (ROS). This underscores the necessity to explore the molecular mechanisms by which weak RF fields in mid-range WPT can affect cellular processes. The present study investigates the effects of 6.78 MHz RF at 10 μT on human umbilical vein endothelial cells (HUVEC) *in vitro* using RNA sequencing and proteomic analyses.

Study design and implementation:

HUVECs were exposed to the described RF field (10 μT at 6.78 MHz) for 72 hours, with sham-exposed cells serving as controls. Researchers assessed cell number, apoptosis, ROS levels, and altered gene expression at the RNA and protein levels using transcriptomic and proteomic approaches. For selected candidates with altered gene expression, omics data were validated using quantitative PCR. Based on omics data, a KEGG (Kyoto Encyclopedia of Genes and Genome) pathway enrichment analysis was conducted. The KEGG analysis statistically determines whether specific pathway components are overrepresented in comparison to a normal expression profile.

Results:

RF exposure resulted in a significant increase in cell numbers and a significant reduction in apoptotic cells. ROS homeostasis was disrupted, with a significant decrease in superoxide anion levels. A total of 101 differentially expressed genes (transcriptomics) and 136 differentially expressed proteins (proteomics) were identified. In terms of molecular function, these differentially expressed genes (DEGs) and proteins (DEPs) were primarily enriched in oxidoreductase activities, aldo-keto reductase (NADP) activities, and malic enzyme activities. KEGG analysis revealed significant enrichment of several canonical pathways, including energy metabolism (pyruvate metabolism and pentose phosphate pathway), focal adhesion pathways, folate biosynthesis, and PI3K-Akt signaling pathways at both transcriptional and translational levels. Key genes related to NADPH/NADH homeostasis, including ME1 (malic enzyme 1) and NNT (nicotinamide nucleotide transhydrogenase), were significantly altered in expression following RF exposure. Components of the folate biosynthesis pathway, including AKR1B, AKR1C, and SPR, were significantly upregulated. The folate biosynthesis pathway is not only a presumed NADPH production pathway but also serves as a key component for maintaining the BH4/BH2 (tetrahydrobiopterin/dihydrobiopterin) balance. A higher BH4/BH2 ratio is known to favor ROS detoxification, reducing oxidative stress and promoting cell proliferation.

Conclusions:

The study's results indicate that RF (10 μT at 6.78 MHz) modulates various pathways and enzymes that regulate NADPH levels, ROS homeostasis, and apoptosis, both directly and indirectly. Uncontrolled growth and apoptosis evasion are hallmarks of all cancer cells, regardless of origin or type. Numerous studies suggest that regenerating and maintaining high NADPH levels plays a pivotal role in tumor formation. The two enzymes, ME1 and NNT, directly involved in the citric acid cycle and the electron transport chain, were significantly elevated following RF exposure. Both enzymes are dysregulated in various cancers and are associated with disease progression and prognosis. Aldo-keto reductases (AKRs) and sepiapterin reductase (SPR) are critical enzymes in BH4 biosynthesis. Numerous studies have shown that AKRs and BH4 synthesis possess antioxidant properties, protecting cells from ferroptosis. Another notable instance of tumorigenic factor upregulation is the alteration of the PI3K-Akt signaling pathway. Effectors such as PKN, CCND1, and VEGF, associated with tumor growth and vascularization, were significantly increased. According to the authors, the upregulation of various pro-tumorigenic factors indeed suggests that applying RF in the mid-range (e.g., for wireless power transfer) poses a health risk. The study provides robust evidence that current safety standards, based solely on the thermal effects of radiofrequency electromagnetic fields, are inadequate. Immediate action, including changes to existing guidelines, is warranted. (RH)

Mechanisms of RF-EMF

Impairment of the microtubular structure after GSM-modulated RF radiation exposure

Čermak AM, Ilić K, Pavičić I. Microtubular structure impairment after GSM-modulated RF radiation exposure. Archives of Industrial Hygiene and Toxicology. 2020 Sep 1;71(3):205-10. https://doi.org/10.2478/aiht-2020-71-3267

Numerous biological effects claimed to be caused by radiofrequency (RF) radiation are of questionable significance for living organisms. However, RF radiation has been found to interact with various apoptosis pathways in living cells. A number of studies have also investigated its genotoxic and other effects on the cell cycle, enzyme activity, gene expression, DNA, oxidative stress and chromosomes. There must be a physical mechanism for RF energy to affect physiological functions or cause disease in humans or animals. This mechanism should explain how the forces exerted by electric and magnetic fields or charged particles alter molecules, chemical reactions, the cell membrane or biological structures. This mechanism could be linked to microtubule dynamics. It is known that the assembly and disassembly of microtubules occurs at specific times in the cell cycle and that the dynamic exchange of charged tubulin subunits influences the movement of cytoplasmic vesicles and organelles such as mitochondria or chromosomes during mitosis. The dynamic instability of microtubule arrangement controls many aspects of cell proliferation, so it stands to reason that microtubules might be suitable for studying bioelectromagnetic effects. The aim of the study was to investigate whether weak 915 MHz GSM-modulated RF radiation affects microtubule structure and influences normal cell growth.

Study design and implementation:

The Chinese hamster fibroblast cell line (V79) was used due to its known properties and frequent use in cytotoxic studies. V79 cells were exposed to a GSM-modulated field in a Gigahertz Transversal Electromagnetic Mode cell (GTEM cell, ETS-Lindgren) for 1, 2 and 3 hours.

An Anritsu 2721B signal generator combined with a Polaris RF 2722 power and signal modulator (RF Micro Devices) generated the electromagnetic field (EMF). The electric field strength was set to 10, 20 and 30 V/m (265 mW/m², 1.06 W/m², 2.39 W/m²), and the average specific absorption rate (SAR) was calculated to be 0.23, 0.8 and 1.6 W/kg.

Each exposure protocol was performed on three independent cell samples. In addition to the negative control, irradiated cells treated with colchicine were used as positive controls. Colchicine is an antimitotic agent that attaches to free tubulin subunits and suppresses the polymerization and destruction of microtubules. The temperature of the culture medium was measured continuously using a temperature sensor. The temperature did not rise during irradiation and was maintained at 36.3 °C, which corresponds to the physiological cell temperature. Microtubular proteins in irradiated cell samples as well as negative and positive control cell samples were determined by indirect immunocytochemical analysis. A complex of a primary IgG anti-β-tubulin antibody produced in the mouse to label microtubular proteins and a secondary antibody representing a conjugate of anti-mouse IgG and fluorescein isothiocyanate was used.

Microtubule damage was assessed by determining the structural differences in the irradiated cells. The changes identified as granular fluorescent clusters were compared with those observed in positive control cells. This granular structure indicates that the microtubule fibers are highly dispersed and therefore damaged. To measure the cell proliferation rate, cells from each group were seeded on 24-well plates and counted daily under a light microscope up to six days after exposure.

Results:

Three hours of irradiation led to considerable damage to the microtubules (independent of the field strength, i.e. approximately the same effect at 10 V/m as at 30 V/m). With shorter irradiation, the microtubules developed normally and did not differ from the negative controls.

Three days after the three-hour exposure, the cell count was significantly lower than in the negative control ($p < 0.05$). A two-hour exposure to 20 and 30 V/m (corresponding to 0.8 and 1.6 W/kg SAR) also led to a significantly lower proliferation rate on day 3 after exposure. However, on day 4 after exposure, cell counts returned to normal in each exposed group.

Conclusions:

The results show that 915 MHz radiation affects microtubular proteins of V79 cells in a time-dependent manner. This confirms the hypothesis that electromagnetic fields in the GSM frequency range could interfere with the mechanisms that drive the cytoskeletal network, since this process relies on the electrical charge of the tubulin subunits. Microtubules as part of the cytoskeleton fulfill the basic requirements for the onset of a so-called „Fröhlich resonance“ (synchronized electromagnetic oscillations within a system). In a healthy cell, this endogenous electromagnetic field is perfectly balanced, but external electromagnetic fields might disturb it. The results of this study show that the effects of radiation on the microtubules do not depend significantly on the electric field strength and the corresponding SAR. Further studies are needed to better understand these processes. (AT)

EMF and microtubules

No observable non-thermal effect of microwave radiation on microtubule growth

Hammarin G, Norder P, Harimoorthy R, Chen G, Berntsen P, Widlund PO, Stoij C, Rodilla H, Swenson J, Brändén G, Neutze R. No observable non-thermal effect of microwave radiation on the growth of microtubules. Scientific reports. 2024 Aug 7;14(1):18286. https://doi.org/10.1038/s41598-024-68852-3

The question of whether constant exposure to radio frequency (RF) radiation can have negative effects on health is the subject of considerable debate and controversy. Public interest in the widespread use of cell phones and their base stations is particularly high. One known effect of microwaves is heating. The guidelines for wireless devices therefore focus on the thermal response. Since the thermal effects are very strong, the non-thermal effects of microwave radiation may be overlooked. So far, the studies on non-thermal effects of microwaves on cells have not been reproducible, and explanations for this problem have been offered.

Tubulin is a protein that is an essential component of the eukaryotic cytoskeleton and exists in solution as a dimer of two globular proteins, α- and β-tubulin. In the presence of guanosine triphosphate (GTP, an important cellular metabolite), these dimers assemble into dynamic polymeric tubes that are about 24 nm in diameter and can be up to several micrometers long. Microtubules are crucial for cellular organization, motility, transport and mitosis. Microtubules are also dynamically unstable as they are constantly assembled and disassembled, leading to phases of rapid growth interrupted by phases of rapid shortening.

Since microtubules are highly polar and in some respects can be thought of as having similar properties to radio antennas, but on a micrometer scale, it was hypothesized that they are sensitive to non-thermal effects of microwave radiation. To investigate the non-thermal influences of RF radiation on microtubule growth, the authors of the study discussed here measured the polymerization of tubulin in response to electromagnetic radiation at 3.5 GHz, 20 GHz and 29 GHz, which corresponds to the frequencies used for mid- and high-band 5G, but only as pure frequencies, i.e. without the typical 5G signal modulation (pulsed).

Study design and implementation:

Electromagnetic fields were applied inside a flow cell using a waveguide powered by a signal generator (Anritsu MG3694C). A flow cell based on a parallel plate waveguide was built specifically to transmit the EMF to the sample.

The 3.5 GHz, 20 GHz and 29 GHz frequencies were radiated at a maximum power of 166 mW, resulting in an electric field of 600 V/m (SAR 300 W/kg) for 3.5 GHz, 1800 V/m (SAR 2700 W/kg) for 20 GHz and 1900 V/m (SAR 2900 W/kg) for 29 GHz, but lower powers were also used. The irradiation lasted only a few seconds.

An infrared camera characterized the spatial distribution of sample heating, measuring the optical density (O.D.) of the sample at the point where heating by the microwave field was strongest. The simultaneous measurement of the optical density and the temperature of the sample made it possible to characterize both thermal and non-thermal reactions.

Tubulin was extracted and purified from porcine brain. It was purified using a protocol that produces tubulin free of microtubule-associated proteins (MAPs). A microspectrophotometer was used for light absorption measurements of microtubule opacity under the influence of 3.5 to 29 GHz microwave radiation. Tubulin polymerization was monitored by measuring the increase in absorbance at 365 nm over time.

Results:

The scientists found that the growth curves of microtubules in samples irradiated at 20 GHz and 29 GHz differed from the growth curves observed at the same temperature without microwave exposure. Samples irradiated at 3.5 GHz did not show this discrepancy. However, these apparent non-thermal effects could be proven to be purely thermal effects with additional control studies, as heating the tubulin sample with laser or infrared light caused the same altered growth curves.

Conclusions:

The purpose of this work was to determine whether the application of microwave fields affects microtubule kinetics beyond the known effects of heating. Tubulin is highly polar, and there are several studies showing that microtubules can align in continuous or oscillating electromagnetic fields. The authors agree with the conclusion of a previous study using 2.45 GHz microwave radiation that microwaves do not alter the rate of tubulin polymerization into microtubules. The maximum field strength used in this study (~ 2 kV/m) is eight orders of magnitude above the signal strength typically associated with cell phone networks (~ -60 dBm). It is possible that the measurements came close to revealing subtle non-thermal effects of microwave radiation, but lacked statistical sensitivity.

(This study used a similar signal generator to the Cermak (2020) study also discussed in this issue, which also investigated EMF effects on microtubules. However, this study only used pure microwaves, whereas the Cermak (2020) study used GSM modulated, i.e. pulsed microwaves. In addition, this study used very high power levels (600 to 1900 V/m), which heated the sample in the flow chamber by several degrees within a few seconds, although the authors claimed to be interested in non-thermal effects. Cermak 2020 used much lower powers (10 to 30 V/m), which did not lead to any measurable temperature increase, and the irradiation lasted 2 or 3 hours. This study (Hammarin 2024) examined isolated microtubules in buffer solution, whereas Cermak 2020 examined live cells and pharmacologically blocked the effects on microtubules as a positive control. Isolated microtubules may not have the same properties as microtubules embedded in a cellular architecture. If they are indeed part of a „computational circuit", their isolated observation would be comparable to experiments on isolated transistors, which only have the capacity for computation or logic gating as part of a circuit. The title of this study is therefore misleading, as the gain in knowledge is minimal and does not exclude non-thermal effects of pulsed microwaves on microtubules, editor's note.) (AT)

Addresses for additional reliable information

Diagnose-Funk e.V. - Environmental and consumer organization for protection from electromagnetic radiation (Germany):
Website: diagnose-funk.org
Email: info@diagnose-funk.de

Microwave News (USA):
Website: microwavenews.com
Email: louis@microwavenews.com

Prof. Joel Moskowitz, Director of the Center for Family and Community Health, School of Public Health, Berkeley (USA):
Institute Website: publichealth.berkeley.edu/people/joel-moskowitz
EMF Website: www.saferemr.com

Prof. Devra Davis (USA):
Website: ehtrust.org
Email: info@ehtrust.org

Prof. Igor Belyaev, Biomedical Research Center of the Slovak Academy of Science, Department of Radiobiology:
http://www.biomedcentrum.sav.sk/research-departments/department-of-radiobiology/?lang=en
Shortened Link: kurzlinks.de/belyaev

Blog by Prof. Darius Leszczynski (Finland):
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