

ElectrosmogReport

Expert information on the significance of electromagnetic fields for the environment and human health



Effects of RF and ELF electromagnetic fields

Comparing DNA damage induced by mobile telephony and other types of man-made electromagnetic fields. By: Panagopoulos, DJ. Published in: Mutation Research – Reviews in Mutation Research. October 2018; 781: 53–62. <https://doi.org/10.1016/j.mrrev.2019.03.003>

The number of studies that demonstrate adverse effects of electromagnetic fields (EMF) on organisms has increased tremendously. Hundreds of peer-reviewed studies show a variety of effects, in particular, DNA damage. The latter is associated with cancer, neurodegenerative diseases, infertility and many other adverse effects. Among these peer-reviewed studies, especially those that use commercially available cell phones instead of EMF simulators as an RF radiation source show adverse effects of electromagnetic fields. The author of the present review analyzed a large number of publications from the scientific literature. In his review, he found that out of 71 studies that used real-life exposure scenarios 68 showed significant effects of electromagnetic fields. Sixty-eight out of seventy-one corresponds to 95.8%. These effects include, among others, reduced fertility, DNA damage and cell death, memory problems and impairment of general cognitive skills as well as heart rate changes. Only 50% of the studies that used simulated signals as a radiation source showed adverse effects of electromagnetic fields. The aim of the present study was 1) to analyze other related studies and 2) to directly compare DNA damage caused by six different human-made EMF sources. For the experimental part of the study, fruit flies (*Drosophila melanogaster*) were investigated.

Study design and procedure:

The research group of the author studied six different human-made EMF sources: 900 MHz GSM (2G), 1800 MHz GSM (2G), 50 Hz ELF magnetic field with a flux density of 0.1

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mT, 1.1 mT and 2.1 mT as well as a pulsed electrical field (PEF; 8 kHz; 44.4 Hz pulse repetition frequency, 400 kV/m). This PEF is similar to atmospheric electricity, which is generated by lightning activity. Ten male and female fruit flies each were included in an experimental group. The exposure durations and exposure levels were as follows: GSM radiation at 900 or 1800 MHz for 6 minutes every 24 hours (a total of 36 minutes) with a cell phone in speech mode and in contact with the glass containers in which the fruit flies were kept. The radio-frequency radiation exposure level was 0.378 ± 0.059 mW/cm². The exposure level of the ELF electric field was 19 ± 2.5 V/m and the ELF magnetic field 0.9 ± 0.15 mG at GSM 900 and ca. 30% lower at GSM 1800. (Editor's note: In telecommunication, ELF signals are present in the form of pulses and modulations, even though the actual information is transmitted with radio-frequency radiation.) The maximum SAR value of the cell phone used was listed by the manufacturer with 0.89 W/kg for the head. The exposure to the 50 Hz ELF magnetic field was continuous for 5 days (120 hours). The PEF was activated every 30 minutes every 2 hours for 5 days (a total of 30 hours). As a control, there was a sham-exposed group for each exposed experimental group. After exposure, the ovaries of the animals were analyzed for DNA damage induced by the different types of electromagnetic fields.

Findings:

The electromagnetic fields emitted by cell phones were significantly more harmful to health than the other types of electromagnetic fields. GSM 900 or GSM 1800 with a total exposure duration of 36 minutes caused DNA breaks in up to 50.16% of the egg chambers in the ovaries of the exposed females. The 50 Hz magnetic field exposure caused this type of DNA damage in only 7.52% of the cases with a total exposure duration of 120 hours. The pulsed electric field (PEF) damaged 2.74% of the study animals with a total exposure duration of 30 hours. In comparison to the sham-exposed groups, this corresponds to an increase in DNA damage of 669.6% for GSM EMF, 114.8 % for 50 Hz ELF MF and 47.7% for PEF. These results show that electromagnetic fields from real-life cell phones are much more bioactive than from other EMF sources. In particular, they are much more bioactive than 50 Hz ELF magnetic fields, which had been claimed to be carcinogenic long before the debate about wireless communication technologies. Even though a direct comparison is not possible, cell phone EMFs are significantly more bioactive than previously tested stress factors such as etoposide, staurosporine, dehydration or malnutrition.

Conclusions:

The publication suggests that both radio-frequency (RF) and extremely low frequency (ELF) electromagnetic field emissions from real-life cell phones contribute to the biological activity. The constantly changing levels of radiation exposure are an extremely important factor for the effects of polarized electromagnetic fields on biological systems and health. All wireless devices (cell phones, WLAN, cordless phones) use radio-frequency (RF) electromagnetic fields for signal transmission and extremely low frequency (ELF) electromagnetic fields (up to 3000 Hz) for modulation. Furthermore, the exposure levels constantly fluctuate during cell phone use because the levels change with the location, the number of users within a cell, the conductivity of the atmosphere, etc. As a result, the average exposure level can be exceeded by 20–30%. The newer the cell phone generation, the more data can be transmitted. And with each new generation (3G, 4G, 5G), the variability and complexity of the signals increase.

The author concludes that the high level of signal variability and complexity makes it impossible for organisms to adapt. Experimental data and theoretical calculations show that the most important physical parameters in the interaction between electromagnetic fields and biological activity are: 1) polarization, 2) ELF components, 3) field strength / intensity, 4) exposure duration and 5) field variability.

The findings of the present study demand that the exposure to electromagnetic fields cannot only be defined by frequencies and average exposure levels, but maximum and minimum intensities, variations in frequency, pulsed or continuous wave patterns as well as modulations and polarizations also have to be considered. Therefore, the author demands that real-life electromagnetic field exposures and not simulated signals should be used in experiments. Furthermore, he believes that stricter exposure limits and a more intelligent deployment of the technology should be used to drastically reduce the exposure to humans and animals.

Editor's note:

The above study could provide insight into why the scientific debate about the impact of electromagnetic fields on health is currently so controversial. It is especially important to define uniform requirements for the sources of electromagnetic fields in scientific studies. When variability as well as modulation play such an important role, as indicated in this publication, these factors have to be considered in all scientific studies. (RH)



Effects of RF radiation on the brain

Long-term exposure to 835 MHz RF-EMF induces hyperactivity, autophagy and demyelination in cortical neurons. By: Kim JH, Yu DH, Huh YH, Lee EH, Kim HG, Kim HR. Published in: Scientific Reports. December 2016; 7: 1–12. <https://doi.org/10.1038/srep41129>

The exposure to wireless cell phone radiation is increasing worldwide. Any effects on the central nervous system (CNS) are of particular interest because cell phones are frequently held very close to the head and thus cause an immediate exposure. The present study looks at the effect of radio-frequency electromagnetic fields (RF-EMF) on cortical neurons. The cortex is a highly developed region in the human brain, where most of the actual information processing takes place. This includes sensory functions (e.g. auditory, visual, olfactory, tactile) as well as cognitive functions (e.g. mental functions, memory-related problem solving, speech comprehension). Anomalies in the cortical region have been connected to various neurodegenerative diseases such as Alzheimer's disease and Lafora disease. The focus of this study was the mechanism of autophagy within cortical neurons. Autophagy is a cellular degradation process, which is responsible for the degradation of damaged cell organelles or unusual protein aggregates. If autophagy is suppressed, this can contribute to the further development of cancer, neurodegenerative diseases and infections and is a hallmark of aging. The study was carried out on mice.

Study design and procedure:

A total of 12 6-week-old male mice were used. They were divided into 2 groups. The exposed group received radiation at 835 MHz with a whole-body SAR value of 4.0 W/kg for 5 hours daily over 12 weeks. The other group was only sham-exposed. After exposure, the behavior of the mice was assessed, using the "rota rod" (rotating cylinder) performance and open field test. The rota rod test analyzes motor dysfunction, especially coordination and balance. The open field test is used to assess fear as a response to a new environment as well as the motivation to move. Thereafter, the cortex of the animals was analyzed. Quantitative PCR (polymerase chain reaction) analysis was used to evaluate the gene expression (protein synthesis based on genetic information; transcription and translation) of different autophagy-related genes. This was then checked with Western blot analysis. In addition, the tissue sections were assessed using electron microscopy.

Findings:

The rota rod test could not find any different behavior in the exposed animals compared to the sham-exposed ones. In contrast, the open field test showed that both the total distance moved and the total duration movement were significant-

ly increased in the exposed animals. These findings point to hyperactivity in the exposed mice. The gene expression analysis found that a series of autophagy-related genes were significantly upregulated as a response to RF electromagnetic field exposure. The transcription rate was 1.5 to 2.5 times higher. At the protein level, Western blot analysis confirmed the results of the quantitative PCR analysis. The two examined proteins LC3B-II and Beclin-1 were significantly increased after exposure. This is an indication for an elevated autophagy as a response to exposure. The electron microscope analysis clearly showed elevated autophagy (autophagosomes, autolysosomes) in the cortical neurons after exposure. Even though no signs of apoptosis (programmed cell death) were found, the exposure caused damage to the cortical neurons. The research group observed changes in the myelin sheaths of axons. The defective myelin sheaths had a frayed lamellae structure as well as unusual myelin protrusions.

Conclusions:

RF electromagnetic fields (835 MHz, 4.0 W/kg SAR, 5 hours per day for 12 weeks) caused hyperactivity in the study animals, induced autophagy in cortical neurons and damaged the myelin sheath of neurons. It is interesting to note that both Alzheimer's disease and Lafora disease are mainly caused by impaired autophagy. The data of the study suggest that autophagy acts as a protective mechanism against RF exposure, which causes cellular stress. The RF exposure may prevent the cells from dying. It is not clear how a higher exposure level to radio-frequency radiation would affect the rate of cell death. According to the authors, additional studies are needed to examine which impact, for example, a 3-months exposure or some other exposure condition might have on the death rate of neurons. The data also show that the myelin sheath was damaged by RF radiation exposure. This fatty substance, which surrounds axons, acts as an electrical insulator and is essential for the transmission of electrical signals across the nervous system. Myelin sheath impairment is associated with multiple sclerosis. (RH)



Effects of 5G frequencies

Additive effects of millimeter waves and 2-deoxyglucose coexposure on the human keratinocyte transcriptome. By: Aite M, Zhadobov M, Soubere Mahamoud Y, Martin C, Le Dréan Y, Habauzit D, Sauleau R. Published in: Plos One. 2016; 11(8): e0160810. <https://doi.org/10.1371/journal.pone.0160810>

Millimeter waves refer to microwaves within the frequency band from 30 to 300 GHz. Most likely 5G networks will be operating in this frequency range. It is expected that 5G net-

works will be deployed nationwide beginning in 2020. Therefore, effects of millimeter waves on humans and the environment have to be promptly evaluated. Some publications describe pain-relieving effects of millimeter waves as well as effects on inflammatory processes in the body, which suggests an interaction between millimeter waves and the human body. The mechanisms that facilitate the therapeutic effects of millimeter waves, however, are not known. The authors of the present publication studied the effect of 60 Hz millimeter waves on skin cells. In a second step, they mimicked the so-called Warburg effect. This effect is about a switch in glucose metabolism, whereby ATP is produced anaerobically via lactic acid instead of aerobically via the citrate cycle. This metabolic switch has been observed in various cancer cells. Finally, the so-called transcriptome of skin cells was analyzed. The transcriptome is defined as the sum total of all RNA molecules within a cell at a given point in time. Each single RNA molecule represents a read gene. A transcriptome analysis reveals any change in the reading of the genome and thus provides information for any change in protein synthesis.

Study design and procedure:

Since millimeter waves have a relatively low penetration depth in tissue, the scientists investigated skin cells. In the in vitro experiments, cells were cultivated in cell culture dishes outside the body. The scientists used primary keratinocytes (dominant skin cell type) of the HaCaT cell line. This cell line is an immortal keratinocyte cell line, which still shows characteristics of primary keratinocytes; however, it is easier to cultivate. The cells were exposed with 60 GHz millimeter waves at 20 mW/cm² over 3 hours. In a second step, the cells were treated with 20 mM of 2-deoxyglucose to mimic the Warburg effect. 2-deoxyglucose inhibits the aerobic ATP production in mitochondria (aerobic glycolysis). Finally, 4 different experimental conditions were compared to each other: sham-exposed, exposed, sham-exposed + 2-deoxyglucose, exposed + 2-deoxyglucose. The reading behavior of the genes was analyzed through microarrays. Those that showed a change in their reading behavior were subjected to RT-PCR analysis.

Findings:

Only the treatment with 2-deoxyglucose, but not with millimeter waves had an effect on the intracellular ATP concentration. This in turn suggests that millimeter waves do not enhance the metabolic stress caused by 2-deoxyglucose. After this observation, the effect of the millimeter waves on the transcriptome was investigated. There was no difference between the exposed and sham-exposed cells. The treatment with 2-deoxyglucose (comparison between sham-exposed and sham-exposed + 2-deoxyglucose) resulted in an altered expression of 665 or 770 genes (depending on a statistical threshold level). After that, the double treatment with millimeter waves

and 2-deoxyglucose was analyzed (comparison between exposed + 2-deoxyglucose and sham-exposed + 2-deoxyglucose). With RT-PCR analysis, 6 genes were identified that confirm an effect of millimeter waves during metabolic stress.

Conclusions:

The observation that millimeter waves do not affect the cellular ATP concentration, the authors interpret as evidence that they do not affect mitochondria. From the double treatment group, 5 out of the identified 6 genes are associated with signal pathways of cell surface receptors. This may suggest that millimeter waves in case of a cancer-like metabolic switch (Warburg effect) can change the cell surface. Furthermore, this also shows that cell-to-cell communication is involved. Two of the genes influence very important signal cascades, namely the RAS/RAF and the JAK/STAT pathway. Both signal pathways are associated with cancer development. The scientists call for further studies, especially for millimeter waves and chronic exposure, to better assess possible risks. (RH)



Effects of microwave radiation on male fertility

Impact of 2.45 GHz microwave radiation on the testicular inflammatory pathway biomarkers in young rats: the role of gallic acid. By: Saygin M, Asci H, Ozmen O, Cankara FN, Dincoglu D, Ilhan I. Published in: *Environmental Toxicology*. 2016; 31: 1771-1784. doi:10.1002/tox.22179

Over the last years, a multitude of electronic devices have made our modern life easier. Electromagnetic radiation – emitted by different sources such as wireless networks, cell phones or microwave ovens – impacts biological systems. Electromagnetic radiation penetrates all tissues of the human body. Testicles are very susceptible to, for example, heat, inflammation or radiation, which may lead to the death of germ cells. The present study aimed to investigate the effect of 2.45 GHz electromagnetic fields (frequency range of Wi-Fi routers) on the pathological and structural changes in the testicles of rats. In addition, the authors analyzed if gallic acid can reduce the effect of 2.45 GHz radiation. Gallic acid is a naturally occurring plant phenolic acid, which can frequently be found in prepared beverages such as red wine, green tea, coffee and pomegranate juice. Gallic acid (GA) has a broad spectrum of biological activities, including antioxidant and anti-inflammatory properties.

Study design and procedure:

For this study, young male Sprague-Dawley rats were chosen. A total of 48 animals were divided into 4 groups (12 animals each per group): sham-exposed, EMF-exposed, EMF-

exposed + GA, GA) The study animals were exposed to 2.45 GHz radio-frequency electromagnetic fields for 3 hours per day over 30 days. The whole-body SAR value was 3.21 W/kg. After the 30-day exposure period, tissue samples were removed from the testicles of the animals for analysis. Beside the histological analysis, the redox status of the tissues (MDA, TAS, TOS, OSI) and various inflammatory markers (PGE2, CGPR, IL-6) were also determined. Malondialdehyde (MDA) is produced by the oxidation of polyunsaturated fatty acids and serves as a marker for oxidative stress. The total oxidant status (TOS) provides the oxidative capacity of a sample. TOS is given in the unit of H_2O_2 equivalent per liter. Conversely, the total antioxidant status (TAS) provides the antioxidant capacity of a sample. TAS is given in the unit of Trolox equivalent antioxidant capacity per liter. The oxidative stress index (OSI) is the ratio of TOS to TAS.

Findings:

The weight of the study animals did not change through the radiation exposure. First, the parameters of oxidative stress were examined. Both MDA and TOS levels were statistically significantly increased in the EMF-exposed group compared to controls. The administration of gallic acid decreased the EMF-induced effect of increasing TOS levels. The TAS analysis shows a similar picture: the EMF-exposed group had a lower TAS level than the sham-exposed group. The administration of gallic acid in the EMF-exposed + GA group could at least partially compensate the decrease in TAS by significantly increasing the TAS level. Compared to the sham-exposed group, the OSI value was elevated in the EMF-exposed group and lower in the EMF-exposed group + GA. The testicular histology was normal both in the sham-exposed group and the gallic acid group. In the EMF-exposed group, slight to mild histopathological appearances such as vascular congestions, edemas and dying sperm were found. Three animals of the EMF-exposed group showed a significant reduction in sperm formation in their seminiferous tubules. The spermatid density was lower in the EMF-exposed group compared to all other groups. The administration of gallic acid in the EMF-exposed group + GA was able to significantly improve the EMF-induced histopathological appearances.

In the EMF-exposed group, the analysis of inflammatory markers showed a statistically significantly increased concentration of CGRP and PGE2 in parts of the testicular tissue. For the marker IL-6, no differences were found among the 4 study groups.

Conclusions:

The findings of this study suggest that electromagnetic radiation may cause degeneration in testicular cells and sperm formation. In this context, oxidative damage and inflammatory processes play a key role. This mechanism could be a cause for infertility. Gallic acid may have a protective effect for testicles with regard to 2.45 GHz radiation. (RH)



Effects on reproductive organs

Effects of mobile phone exposure on metabolomics in the male and female reproductive systems. By: Altun G, Deniz ÖG, Yurt KK, Davis D, Kaplan S. Published in: *Environmental Research*. February 2018; 167: 700–707. <https://doi.org/10.1016/j.envres.2018.02.031>

As technology continues to evolve, humans are more and more frequently exposed to a broad spectrum of electromagnetic fields (EMF). The present review paper aims to shed light on the effects of EMF-induced metabolic changes in female and male reproductive organs in the context of the currently available scientific body of evidence. Studies in humans and animals have identified a range of adverse health effects, which can be induced by electromagnetic fields and call for another evaluation. In vivo (in living organisms such as rodents) and in vitro (in a test tube, e.g. in cell cultures outside a living organism) studies show that EMF exposures can change cellular homeostasis, activate calcium channels and influence hormonal functions, reproductive functions and fetal growth in animals. EMF effects can be divided into thermal and nonthermal. Thermal effects are fairly well researched and understood. Molecules inside the body start to oscillate because of EMF exposure, rubbing against each other and thus producing heat. Nonthermal effects are much less well researched and the exact mechanisms are unknown. The formation of reactive oxygen species, which causes oxidative stress, is one possible mechanism.

Study design and procedure:

The authors of this review paper analyzed more than 100 studies to summarize the current state of knowledge in this research area.

Findings:

On a cellular level, EMF-induced changes can lead to free radicals, calcium-mitigated growth disorders, protein misfolding and DNA damage. A mechanism that might explain how free radicals are formed by EMFs is the Fenton reaction. In the presence of iron and EMFs, hydroxyl radicals are produced. The reactive oxygen species (ROS), among other things, lead to oxidative stress inside the cells. Furthermore, a series of studies show adverse effects of EMFs in both sexes on sex hormones, functions of the primary reproductive organs, fetal growth and pregnancy. In the context of EMF-exposed testicles, oxidative stress plays an important role. While some studies point to negative effects of EMFs on the male reproductive system, other studies found partial or no effects. The authors of this review paper attribute these inconsistent results to the use of different frequencies, power densities and exposure durations. Furthermore, induced magnetic fields are not standardized. There is increased evidence, however, that cell phone radia-

tion can cause structural and functional damage in testicles, changes in semen parameters, lower sperm concentrations and male fertility. Due to their lack of antioxidant protection, sperm are particularly susceptible to the action of reactive oxygen species. As a result, EMFs can induce oxidation in sperm membranes. Sperm motility, an important parameter of male fertility, is also adversely affected by reactive oxygen species. A study with 304 male participants showed that 65.7% of those participants without a cell phone had a motile sperm rate above 50%. Only 17% of those participants who had been using their cell phone for 2 years had a motile sperm rate above 50%. Apoptosis (programmed cell death) is another effect EMFs can have on male fertility. Again, the findings of different studies are not consistent. However, there is evidence that the exposure to electromagnetic fields can initiate apoptosis.

In one study, this resulted in a smaller diameter of the seminiferous tubules and a thinner layer of the epithelial cells. The formation of sperm occurs in the seminiferous tubules. Furthermore, EMFs also impact the hormonal regulation of sperm formation. As a result of EMF exposure, several studies report about lower hormone concentration levels (among others, testosterone), which are responsible for the formation of sperm. There is evidence that Leydig cells (site of testosterone production) are adversely affected by reactive oxygen species. A study with 2110 male patients from a fertility clinic examined the serum concentration levels of different sex hormones. The authors of this study concluded that cell phones have a negative impact on sperm quality and male fertility.

The impact of EMFs on female reproductive organs was also the subject of the present review paper. Both ELF and RF electromagnetic fields can contribute to damage in female reproductive organs. Data from animal and human studies show that EMFs can have negative effects on granulosa cells (auxiliary cells of egg cells, which are important for their maturation), the number of follicles (units of egg cell and auxiliary cells), the endometrium, egg cells and embryo quality. Several studies describe an impact on the differentiation of egg cells as well as follicle maturation due to ELF electromagnetic fields. This can lead to reduced fertility because of reduced ovary storage. RF electromagnetic fields (e.g. 900 MHz, 2450 MHz) can have negative effects on female fertility. RF electromagnetic fields also lead to the formation of reactive oxygen species, which cause oxidative stress, oxidize cell membranes and initiate apoptosis. Among other things, this can damage granulosa cells. And again, the evidence of the currently available studies with regard to female reproductive organs is not clear. For example, there is a study that could not find any negative effects of 2.45 GHz radiation during pregnancy on reproductive organs and the fertility of male or female rats. Experiments with fruit flies, however, demonstrate a significant reduction in fertility after exposure to radio-frequency radiation. With regard to the induction of apoptosis, there are similarities between

EMF-induced fertility disorders in insects and mammals. Like the male hormone balance, EMFs also appear to impact the female hormone balance. One study observed reduced concentration levels of prolactin, estrogen and progesterone in female rats and their offspring that had been exposed to radio-frequency electromagnetic fields during pregnancy. Another study documents that medium and high radio-frequency radiation exposure levels reduce the fertility rate and blastula formation (early embryonic stage) in mice and thus reduce the likelihood of the embryo being embedded.

Conclusions:

Reproductive cells appear to be more vulnerable to ionizing and nonionizing radiation than other cells because they have fast growth rates during cell division. The faster cells grow, the chances for making mistakes during the synthesis of various biomolecules will be greater. To summarize, the radiation emitted from cell phones has a number of well documented negative effects on female and male reproductive organs and can lead to reduced fertility and infertility. The production of reactive oxygen species, which trigger oxidative stress and, among other things, oxidize cell membranes, appears to play a special role. Even though many studies report about structural and functional deficits in testicles and ovaries after EMF exposures, the fundamental mechanisms have not yet been fully explained. The authors demand that, in future studies, exposure parameters should be standardized to be better able to compare findings. (RH)



Effects of microwave radiation on male fertility

Radiations and male fertility (review). By: Kesari KK, Agarwal A, Henkel R. Published in: *Reproductive Biology and Endocrinology*. 2018; 16(1): 118. <https://doi.org/10.1186/s12958-018-0431-1>

Over the past years, an increase in male infertility has been observed in the general population. There are probably different factors such as intense heat as well as exposure to pesticides, radiation, radioactivity and other hazardous substances that contribute to this trend. We are surrounded by ionizing and nonionizing radiation, both of which have a causative effect on spermatogenesis. Particles or electromagnetic radiation that is capable of knocking off electrons from molecules and thereby leaving positively charged residual molecules behind is referred to as ionizing radiation. X-ray radiation, gamma radiation and alpha particles are examples of ionizing radiation. They are much more hazardous than nonionizing radiation because they contain sufficient energy to damage genetic

materials and thus can cause cancer, for example. The authors of the present review paper, however, focus on nonionizing radiation and its effects on male fertility. Nonionizing radiation is divided into 2 main ranges: 1) extremely low frequency (ELF 0.1 Hz – 1 KHz) and 2) radio-frequency electromagnetic fields (RF-EMF, 10 MHz – 300 GHz). The latter type of radiation, for example, is produced by cell phones, laptops and wireless networks as well as microwave ovens. Since RF radiation can now be found everywhere in the environment, it has been included in the list of other environmental pollutants (air, water, soil, noise) and referred to as “electromagnetic pollution” or “electrosmog.”

Beside the brain, testicles are the organ most vulnerable to radiation. Many animal experiments on the use of cell phones show a decrease in sperm count and motility, which points to an impairment of male fertility. One study found comparable results in humans, as well. The continuous use of cell phones is associated with a reduction in sperm concentration levels, motility, morphology and viability. At this time, however, no possible mechanism is known as to how RF radiation affects male reproductive organs and thus may impair fertility. Some of the effects are discussed in more detail by the authors: 1) biophysical parameters of radio-frequency radiation, 2) impact on sperm parameters, 3) role of kinases on cellular metabolism, 4) genome-damaging effect, 5) induction of oxidative stress, 6) effect on the endocrine system of male reproductive organs and 7) protective measures for this type of radiation and recommendations for future use.

Study design and procedure:

In this review paper, independent studies about the effects of radio-frequency electromagnetic fields on male fertility were analyzed.

Findings:

The biophysical parameters describe physical and biological factors that determine the vulnerability of a cell to the effects of radio-frequency electromagnetic fields through measurements of the radiation absorption rate. To elicit a biological response, the electromagnetic field has to pass through the

surface of a given biological system to produce internal fields. The penetration depth depends on a number of factors, including RF parameters (e.g. intensity, field strength), distance to the radiation source from the biological system as well as form and geometry of the biological system. Some studies suggest that radio-frequency radiation is strong enough to penetrate the human skull so that ca. 40% of the radiation can penetrate deeper into the brain. It is assumed that the penetration depth is 4–5 cm. A similar penetration depth is assumed for the testicles. The question remains as to how this type of

radiation can damage cellular components and thus contribute to a higher rate of infertility. DNA damage is one of the greatest problems with regard to infertility or testicular cancer. Since RF radiation is nonionizing, the photons do not contain sufficient energy to break chemical bonds or to ionize biological molecules. It is therefore assumed that RF radiation does not cause direct DNA damage. Indirect mechanisms such as the free radical hypothesis have been proposed to explain the DNA damage. Free radicals and reactive oxygen species will be discussed in more detail further below.

A number of sperm parameters such as sperm quality, sperm count, motility and morphology are adversely affected

by aging as well as lifestyle factors (e.g. alcohol and tobacco consumption). In addition, the use of cell phones or other electronic devices contributes to the worsening of various sperm parameters. In connection with the use of cell phones, various studies observed a decrease in the number of motile sperm, general sperm motility, viability and an increase in reactive oxygen species (ROS) and abnormal sperm morphology. An animal experiment showed a reduced sperm count and a higher percentage of apoptotic cells (apoptosis = programmed cell death) after the exposure to cell phone radiation (from a real-life cell phone as the radiation source) for 2 hours per day for 35 days. Another study showed a reduction in sperm count and motility after the rats had been exposed to a Wi-Fi-activated laptop (7 hours/day for 1 week). Two publications reported that carrying a cell phone in a pant pocket or belt reduces sperm motility. A number of studies could demonstrate that the general use of cell phones results in a lower sperm count and motility, altered morphology and reduced viability. Morphological changes in the

„ In connection with the use of cell phones, various studies observed a decrease in the number of motile sperm, general sperm motility, viability and an increase in reactive oxygen species (ROS) and abnormal sperm morphology.“

testicles could also be demonstrated.

One research group showed that the diameter and weight of the seminiferous tubules (location of sperm formation in the testicles) decreased and the average thickness of the epithelial tissue of the seminiferous tubules was smaller after exposure. Spermatogenesis (sperm development and maturation) is also impaired on a molecular level. During spermatogenesis, the active cell division process is divided into 2 phases: mitotic and meiotic phase. During the mitotic phase, the sperm progenitor cells increase and during the meiotic phase, the chromosome set is reduced (diploid to haploid). After that, the mature sperm develops. Various key molecules, which control the cell cycle, are involved in this intricate process. Cell phone radiation interferes with the cell cycle. As a result, lower numbers of sperm mature and the number of apoptotic sperm are higher. The author's research group was able to show that the activity of one of these key molecules, sperm protein kinase C, decreased after cell phone radiation exposure. Furthermore, the researchers were also able to demonstrate that the activity of another key enzyme, histone kinase H1, also decreased. The concentration level of a third kinase, sperm creatine kinase, increased after microwave exposure. Creatine kinase

plays an important role for the motility of sperm. The authors of this paper point out that three kinases play an important role in cell metabolism and spermatogenesis and that a change in these sperm kinases due to cell phone radiation exposure may lead to infertility.

Beside its impact on enzymes, radiation exposure also affects the testicular hormone balance. Microwave radiation decreases the number of so-called Leydig cells in rats. These cells produce testosterone. When the number of these cells is reduced due to microwave exposure, the testosterone concentration level in the blood serum of rats decreased as a result. Several studies showed that testosterone is indispensable for spermatogenesis as well as the morphology and physiology of seminiferous tubules. Therefore, changes in the testosterone concentration level will have adverse effects on male fertility. Beside this direct impact on testosterone-producing cells, the exposure to radio-frequency radiation can also change the hormone secretion in the pituitary gland. In this process, a whole range of hormones are affected that, among other things, may also impact spermatogenesis and testosterone production. For example, the production of the luteinizing hormone

(LH) and the follicle-stimulating hormone (FSH) are also affected. Both hormones are involved in sperm maturation. The hormone secretion from the pituitary gland is adversely affected, as well. Researchers showed that melatonin concentration levels decreased in the pituitary gland. Melatonin has a so-called antigonadotropic effect, which means that it shrinks the reproductive glands. Moreover, this hormone is an important antioxidant.

Several studies observed that infertile males have damaged sperm DNA. Apart from other lifestyle factors, it could be shown that the chronic use of cell phones damage sperm DNA. In an animal experiment, in which the antenna of a 3G cell phone was located next to the rat testicles (2 hours/day for

60 days), DNA strand breaks in sperm cells were observed. Two additional publications describe DNA damage in sperm or testicular cells when exposed to 2.45 GHz microwave radiation. In vitro samples of human ejaculate that were exposed with 2.45 GHz radiation lead to changes in sperm motility as well as DNA strand breaks. However, radio-frequency radiation is not strong enough to cause genomic damage in case of short-term exposure. It is assumed that the damage occurs as a result of long-term and cumulative effects. Again, it is pro-

posed that oxidative stress plays a key role in the fundamental mechanism of sperm DNA fragmentation.

The impact of nonionizing radiation also affects sperm cell organelles. Microtubules (tubule-like protein complexes) are responsible for diverse functions in sperm. They play an important role in cell division and intracellular transport. In addition, the sperm tail (flagellum) consists mainly of microtubules. Any changes in the conformation of microtubules can result in an altered shape of the flagellum and thus may severely worsen sperm motility. This can lead to infertility. One publication describes changes in the conformation of microtubules after cell phone radiation exposure. Apart from a functioning drive system, sperm also needs energy to be able to move forward. This energy is supplied by the mitochondria of the sperm in the form of ATP (adenosine triphosphate). Scientists found that radio-frequency radiation damages sperm mitochondria, whereby sperm motility is impaired on a different level. Furthermore, mitochondrial damage results in an increased production of reactive oxygen species (ROS).

The association between electromagnetic fields and possible health impacts is the production of reactive oxygen species

„Even small changes in the concentration levels of reactive oxygen species play an important role in the functioning of the sperm head cap and its capability to reach the ovum.“

and the oxidative stress caused by the latter. Oxidative stress refers to a status in which the natural balance between oxidants and antioxidants has been shifted heavily toward oxidants. Free radicals can oxidize lipids, proteins and DNA, which in turn may damage cells, tissues and organs. A research group reported that oxidative stress could be the main factor that causes an increase in sperm DNA damage. Sperm is particularly vulnerable to oxidative stress. Even small changes in the concentration levels of reactive oxygen species play an important role in the functioning of the sperm head cap and its capability to reach the ovum. A publication showed that the concentration levels of reactive oxygen species were significantly increased in rats after cell phone radiation exposure. A number of scientists report that elevated levels of reactive oxygen species represent a cytotoxin and may lead to a loss of motility as well as a lower number and viability of sperm. Several studies show that infertile men have elevated concentration levels of reactive oxygen species and a lower antioxidant potential in their sperm. It is also important that these highly reactive free radicals are sequestered by antioxidants. The body's antioxidant protective mechanism (superoxide dismutase, glutathione peroxidase, melatonin), however, is weakened by radiation exposure.

The effects of radiation therapy on male fertility offer further insight into the impact of electromagnetic radiation. Scientists were able to demonstrate that radiation treatment for testicular cancer has a more harmful effect on fertility than chemotherapy. During the first 50–60 days after a moderate radiation treatment (dose of 1.5–2 Gy), the sperm count was reduced by 50%. The recovery time for a normal sperm volume and count is 9–18 months after a radiation dose of below

1 Gy, 30 months after 2–3 Gy and 5 or more years after 4–6 Gy.

With regard to fertility, the authors recommend to take antioxidants as a protective measure against radio-frequency radiation. Especially the treatment with melatonin reduces oxidative stress and recovers the physiological concentration levels of testosterone. The consumption of green tea, which contains a series of antioxidants, improves the quality of sex cells.

Conclusion:

In total, the authors analyzed a large number of studies. These studies showed that radiation exposure to cell phones, microwave ovens, laptops or Wi-Fi has adverse effects on male reproductive organs. These adverse effects include: reduced sperm count, morphology and motility, increased DNA damage as well as the impairment of protein kinases, hormones and antioxidant enzymes. They are responsible for infertility because of an excess production of reactive oxygen species. The studies suggest that the effects caused by radio-frequency electromagnetic fields depend on physical parameters such as exposure duration, distance to the radiation source, field strength and penetration depth. According to the authors, there are currently no studies available that can explain the true mechanism on how exactly radio-frequency radiation affects male reproductive organs. Furthermore, the harmful effects of radio-frequency radiation have not yet been sufficiently demonstrated in human studies. Therefore, the authors call for further studies to gain better knowledge. They also observe that research findings appear rather limited with regard to possible protective measures against electromagnetic pollution. (RH)