

# Biological effects of electromagnetic waves with emphasis on radio and microwave: An environmental carcinogen

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Human is exposed to a variety of electromagnetic fields from natural and artificial sources. These fields cause the electric field in the body to affect the movement of ions, heat, neuromuscular stimulation, and various effects. The biological effects of these waves depend strongly on the waveform, frequency and angle between the applied fields and the Earth's magnetic field, as well as their continuity or pulsation. Electromagnetic fields caused by conventional devices are at a standard level and appear to be harmless to humans. But the results of research on specific people, such as military personnel or those who live and work near radar stations, high-pressure posts and high-powered telecommunications and radio transmitters, show that they have harmful effects and live nearby they are not risk free.

## Introduction

Today's life on Earth is actually immersing in a sea of natural electromagnetic fields. Over the past century, this natural environment has changed drastically due to the presence of a broad spectrum of expanding synthetic electromagnetic fields. Current applications of communication in the field (terrestrial and aerial), military affairs, sea climbing, as well as in industries (such as metal smelting, steel making), home use and medical fields make people more exposed electromagnetic fields. The effects of low-frequency electromagnetic fields are different from the effects of high-frequency fields. This is because at low frequency the voltage of the current is higher and this is when the living creatures are exposed to them freely and without protection [1]. Electromagnetic energy is absorbed by the body and converted to thermal energy, which increases the body temperature to 1 to 2 ° C if the energy absorption rate exceeds about 4 watts per square meter. Frequencies of about 50 to 80 Hz are usually the most dangerous frequencies for the body. At these frequencies, even very small currents cause significant biological effects [2].

### Fig 1 Electromagnetic wave spectrum.

Therefore, it seems that more attention has been paid by researchers in the field of magnetic fields in recent years to ELF waves, especially at power frequencies (50-60 Hz) [3]. [Figure 1](#) shows the spectrum of electromagnetic waves.

## Productive sources of extremely low frequency

## electromagnetic fields

ELF electric and magnetic fields are produced by natural or man-made sources. Generating ELF fields requires periodic electrical charge fluctuations. When the electric charge is spread over a wide range, it generates the electric field. When the charge is in motion, it generates an electric current and produces a magnetic field. The electric field applies force to all ions in the biological system, and the magnetic field applies force to all the moving ions in the biological system. Some useful applications of ELF fields include induction heating, metal detecting, magnetization, communication, and induction processes including windings, ELF fields as well as in transformers, motors and in medicine for bone healing and magnetic resonance imaging. In some environments, ELF electric and magnetic fields are a by-product of generating, transmitting, distributing or applying electrical power [4].

## Natural sources of electromagnetic fields (radio waves)

Solar radiation and cosmic rays are important sources of extraterrestrial natural fields. Solar explosions and lightning are also other sources of RF radiation. Earth and even the human body transmit heat radiation at intensities of about  $0.003 \text{ W / m}^2$  at frequencies exceeding 300 GHz. Earth like a filter protects us from part of the harmful electromagnetic radiation outside the atmosphere. The electromagnetic waves that pass through this filter are limited to two frequency windows, one in the visible light range and the other in the range of MHz10 to GHz37.5 [5]. Earth's magnetic fields(permanent) consist of the main field and the local field. The Earth's main field is the result of the molten iron moving above the solid inner core of the Earth, and the local fields result from magnetization of the cortical rocks of the Earth. The magnitude of the Earth's magnetic fields varies from about 35 to 70  $\mu\text{T}$  with an average of about 50  $\mu\text{T}$  (500 MG) [4].

## Synthetic sources of RF electromagnetic fields

Telecommunications transmitters, radar systems, and radio and television transmitters produce highly electromagnetic fields that oscillate with high frequencies. Workers working in radio and television news towers are affected by 10 KV / M electric fields and magnetic fields with intensities above 5 mA / m. Microwave ovens are also sources of RF electromagnetic fields production that work with an output power of 600-600 W at 915 and 2450 MHz. These fields are extremely harmful if leaked out. The most important sources of high electromagnetic fields are cell phones. These phones transmit and receive electromagnetic waves in the range of 900MHz to more than one GHz [6]. At frequencies of MHz1 to 1 GHz, electromagnetic energy is absorbed by the body and converted into thermal energy, which increases one to two degrees of temperature if the energy absorption rate increases from about 4 watts per square meter, so the waves at frequencies Nearly MHz 27 and MHz 2450 are used for therapeutic purposes [7].

## How the body absorbs energy from electromagnetic fields

Maximum absorption from an RF field occurs when the electric field direction is parallel to the person's stature. Also, for an average person, the fields with frequencies between 70 and 150 MHz have the highest absorption in the body. In general, the absorption rate at different frequencies varies as follows:

1. Frequencies below 100 kHz cause low energy absorption and low and unmeasurable temperature increase, and their effect is mostly due to induction current and partly nerve stimulation [8].
2. At frequencies above 100 kHz, the absorption is greater. As the frequency increases, the

amount of energy absorbed increases and local absorption increases. At frequencies above GHz 10 the absorption of energy from the electromagnetic field is further limited to the surface of the skin. For this reason at different frequencies different units are used to measure field intensity [6].

The effects studied in humans are divided into two groups: 1- Non-cancerous effects and 2- Cancer effects [4].

The first studies on the possible effects of exposure to electric and magnetic fields were published in former Soviet papers in the 1960s. They have reported on workers in electricity distribution and transmission substations, various mental disorders, cardiovascular, gastrointestinal, and central nervous system problems. Similar studies on electrical installation workers continued until the next decade, with results that were sometimes inconsistent. As there are extensive discussions about changing and lowering current standards among scholars. Therefore, it seems that more attention has been paid by researchers in the field of electric and magnetic fields in recent years to ELF waves, especially at power frequencies (50-60 Hz) [9].

## **A) Non-cancerous effects of extremely low frequency electromagnetic fields**

Studies have shown that low-frequency electromagnetic fields can affect cell growth [10], cell morphology and shape [11] being carcinogenic [8], cell differentiation [12], and programmed cell death [13]. Exposure to low-frequency electromagnetic fields results in increased oxidative stress in chick embryos [14], cultured mammalian cells [15], and human erythrocytes [16]. Increased DNA peroxidation of oxidative stress, including oxidative damage of fats [17], is associated with increased systemic abnormalities and cell death [18, 19]. Investigating the effects of electromagnetic waves on the reproductive system of laboratory animals indicate the role of the electromagnetic field in inducing oxidative mechanisms causing tissue damage and apoptosis in rat endometrial cells [20]. Studies have shown that continuous microwave waves of 20-5 and 6 hours daily irradiation at 2 W / kg with specific absorption per week can impair sperm production in mice [21]. In another study, the observations showed the effect of the electromagnetic field on the immune system by lowering serum and cortisol levels in the group exposed to ACTH (electromagnetism) [22]. Electromagnetic fields with high-energy waves raise local temperatures and, like ionizing radiation, cause cellular damage by creating free radicals and with regard to glomerular dilatation, the articles confirm that electromagnetic fields cause anemia and thus dilute glomeruli to compensate for this decrease [23].

In general, the non-cancerous effects of extremely low frequency electromagnetic fields includes diseases listed in the chart below.

*Fig 2 the non-cancerous effects of extremely low frequency electromagnetic fields*

It should be noted that although a number of studies have estimated that ELF fields produce biological changes, research on health effects is still preliminary and incomplete.

ALS Syndrome: A disease associated with a defect in the motor neurons, which destroys the spinal cord neurons [24].

## **Changes in DNA induced by electromagnetic waves**

The results of experiments in vitro as well as in the body of living organisms confirm the destructive effects of electromagnetic radiation of radio frequency on DNA. In this study, the acute effects of

exposure to 2450MHz waves has been investigated on the breakdown of DNA strands. The results show that the increase in DNA strand breaks occurs in either pulsed or continuous wave types. The researchers believe that these effects could be the result of the direct effect of electromagnetic energy of radio frequency on DNA molecules or the disruption of DNA repair damaged by brain cells. Investigating the effects of HF-EMF waves on DNA showed that GSM signals affect DNA integrity. Overall, the data show that HF-EMF with carrier frequency and GSM signal modulation structure can increase DNA fragmentation and cleavage by affecting the DNA molecule in the human trophoblast cell line [25, 26].

## **The effect of electromagnetic waves on the nervous system**

Many reports have expressed researchers' concern about the effect of radio frequency exposure (RFR) in the range of 300 MHz - 10000 kHz. According to bioelectric researchers, the nervous system function will be disrupted by these microwave waves. Studies of the effects of RFR on the nervous system include many aspects such as: morphology, electrophysiology, neurochemistry, neuropsychology, and psychology. The effect of RFR in an organism will be associated with an increase in temperature in the tissue, which induces a physiological and behavioral thermal response. This response involves neural activity in the central and peripheral nervous system. The effects of RFR on heat regulation have been extensively studied and the effects of RFR on the central nervous system, nerves and glands have also been studied and disorder in nerves and glands function to stress, changes in immune-related responses, and tumor growth were observed under waves [27, 28].

## **The effect of electromagnetic waves on hearing**

Recent studies have investigated the effects of radio frequency radiation (RFR) on neurons, learning and memory on animals. Examine the effects of waves (such as cell phone radiation) on brain electrical activity and its relation to cognitive functions, the damaging effects of waves on the auditory system, and in a series of reports, cases such as fatigue, headache, dizziness, sleep disorder, etc. have mentioned. Proximity to the mobile antenna results in the deposition of relatively large amounts of radio frequency energy in the head. Observations show that the distribution of energy and radiation in the body can be an important factor in determining the outcome of the biological effects of RFR in the body [28-30].

## **Relationship between electromagnetic waves with memory and Alzheimer's disease**

Research shows that very low-frequency magnetic fields (ELF-MF) lead to the accumulation of manganese in the brain, kidney, and liver. Diseases such as Alzheimer's, Parkinson's and Huntington occur due to the accumulation of manganese in the brain that can cause toxicity to the nervous system. The results also showed that exposure to EMF waves affects the biochemical parameters of blood serum. The manganese absorbed from the intestine passes through the lungs to the intestinal veins. The main tissues in which Mn precipitates are the liver, the pancreas, and the muscles. The brain is also the site of accumulation of these toxins, although it is lower than in other parts of the body, which can eventually lead to memory disorders [31, 32].

## **The effects of exposure to electromagnetic waves (ELF-EMF-RFR) on Fertility and Reproduction**

Electromagnetic fields and radio frequency radiation interact with human body tissues and can have adverse effects on fertility and reproduction. Here is a review of evidence of the effects (ELF-EMF-RFR) on many parameters of male sperm function. Although most human and animal studies have been performed on sperm and male fertility factors, there is some research showing the

adverse effects of electromagnetic waves on fertility and abortion in women. According to reports, the use of home electronics and cell phones reduces the fertility potential in men by reducing sperm count, motility and viability, inducing pathological changes in sperm and testicular morphology. The germ formation process is a complex process influenced by many genes and hormones that occur in the testis and may be subject to the specific microwave frequencies currently in use. Research conducted in Year 2006 showed that adult male rats exposed to these fields (one hour per day, for 2 days, 128 mT) had a decrease in testosterone levels and their oxidation induction. A similar experiment in Year 2005 showed that electromagnetic waves with a frequency of 50 Hz (for 4 weeks, 0.2 mT or 6.4 mT) may induce DNA strand breaking in testicular cells and sperm chromatin density in mice. Nakamura and his colleagues in 2000 showed that exposure to continuous microwave waves with a 2.45 GHz wavelength with Energy density 2 mW / cm<sup>2</sup> for 90 min decreased placental-dependent uterine blood flow and increased progesterone in pregnant mice [33-35].

## B) ELF Electromagnetic Fields and Cancer

The World Health Organization has classified electromagnetic waves into category B2 with the probability of carcinogenicity, and numerous research studies are ongoing on the effects of electromagnetic waves and their carcinogenicity, while definitive results have not yet been published. Throughout history, this has been the case for many cases, such as asbestos, and its serious health risks have certainly been confirmed after many years [36]. ELF fields do not have enough energy to affect DNA and gene mutation. Therefore, these sites are not considered to be initiating agents of cancer, and can be considered as contributing or contributing factors to cancer progression. Studies on the cell membrane have focused on gene expression and stress responses, but no theory of the mechanism of progress has been established.

Reported observations of cells in relation to ELF exposure and cancer include:

- Enhancement of growth-related activity of ornithine dicarboxylase enzyme
- Inhibition of human breast cancer cells by melatonin
- Decrease of the inhibitory effect of melatonin on the growth of ELF-induced human breast cancer cells
- The intensifying effects of 60 Hz magnetic fields and ionizing radiations on the production of clastogenic changes in human lymphocytes

Stones has put forward a theory for the development of women's breast cancer from exposure to ELF fields. This theory points to the onset of cancer with DMBA, which is followed by exposure to ELF and which reduces melatonin levels. Because melatonin inhibits estrogen and prolactin, concentrations of these hormones remain at higher levels during ELF exposure, which has a stimulatory effect on endangered root cells [4, 37, 38].

The cancerous effects of electromagnetic fields on humans are generally divided into three categories:

### 1. Leukemia

Studies have shown that electromagnetic waves affect melatonin secretion and the incidence of leukemia. The results showed that the incidence of cancer was higher among residents living near telecommunication antenna masts compared to those living in remote areas [39]. It was also observed that even low-frequency radiation in the long run increased the risk of cancer. Leukemia was the first cancer to be associated with an occupational disease in ELF. And at least 70

epidemiological studies of this cancer have been presented. Most of these investigations were based on job titles and there were judgments about professional categories. The analysis of the studies have shown that there was little risk of leukemia and the researchers were not able to relate these studies to a particular occupation [40].

## 2- Brain cancer

ELF waves have extensive effects on body biology. Because of the electrical nature of the nervous system and neurotransmitters, these waves have effects on the system that are in some cases destructive (4). Most epidemiological studies have placed less emphasis on the association between brain tumors and exposure to ELF fields. Most of these communications are at a relative risk of 0.69 to 1.50 with a high confidence interval. In general, the larger the confidence interval, creates the greater the uncertainty in this study [4]. In a population-based and case-control study in the Rhineland-Palatinate region (including 1.3 million people) of the Federal Republic of Germany, risk factors for brain tumor development were evaluated in 226 cases of primary brain tumors and 418 people were controlled and standard questions were asked and an analysis of occupational risk factors and smoking was provided. No evidence of an increased risk of smoking was found, and for many businesses there was no significant risk factor for occupational factors. Five specific occupational groups were evaluated. But the important point was the significant increase in the risk of brain tumor development related to working in electrical jobs for women (relative risk RR = 5.2) [28].

Author, year		Interpretation
Elaine et al., 1985	1 (0.1-3.7)	Engineers
Tornquist et al., 1989		
McLoughlin et al., 1986	1.2(0.21-3.7)	-
Jutilenin et al., 1990		
Gionel et al., 1993		

**Tab 1 Some of the studies on brain cancer [41].**

These studies permit the same limitation as previously mentioned: Small sample sizes and probability of misclassification in the face of ELF. Four examples of those studies have found the strongest association with neural connective tissue star cells of a subset of 13 Gliomas. One study due to multiple health effects has found an increasing in brain cancer, but there was no increase in leukemia. Two studies have identified increased risk during exposure and the other two studies have revealed a significant linear trend with exposure level. However, these studies are not supported by actual ELF measurements.

## 3. Breast cancer

One of the most important environmental pollutants is electromagnetic waves pollution, which is increasing day by day with the development of technology and the development of telecommunications infrastructure. Numerous studies have been conducted on the biological effects of electromagnetic waves [42]. One of the most important biological effects in research



studies in this field is the effects of electromagnetic waves on the formation of cancer, and especially breast cancer. One of the hypotheses raised in this regard is the rise of breast cancer in industrialized and modern countries. It is hypothesized that increased exposure to Electromagnetic fields (EMF) will decrease melatonin production. Since some studies have shown that melatonin suppresses breast tumors in rats and prevents the proliferation of estrogen-induced human cancer cells (in vitro), thereby increasing exposure to electromagnetic waves and decreasing melatonin levels. It increases the chance of developing breast cancer [43]. There have also been studies of the association between breast cancer and exposure to the electromagnetic field. Breast cancer is rare in men, but unfortunately it is very common in women. Some recent research has also suggested that breast cancer may develop in men who are exposed to electromagnetic waves [44]. In the United States, breast cancer has been seen in more than one case in every 1,000 cases in year. Other studies have done in the United States and elsewhere show that even women who work at home and are exposed to a high electromagnetic field have a high risk of developing breast cancer [45, 46].

## **Measurements made with Extremely Low Frequency (ELF) beams**

1. In a study conducted by Wout Joseph in 2007 at Belgian Kv 0.4 - 11.22 power distribution stations to determine the minimum distance to public places where people were exposed to these ELFs, 637 stations were measured. Of these, 358 were magnetic fields and 279 electric fields were in different locations. The values obtained in the magnetic fields ranged from 0.025 to 47.39  $\mu\text{T}$ . Electric fields were also obtained between 0.1 and 536 V / m. The maximum daily values of magnetic and electric fields were 100  $\mu\text{T}$  and 5 Kv / m, respectively. For stations producing electromagnetic fields above 100  $\mu\text{T}$ , a minimum distance of 0.5 m was obtained. While the mean contact was 0.4  $\mu\text{T}$ , the minimum distance was obtained 5.4 m (daily mean) and 7.2 m (mean annual) [47].
2. Anders Johnsson et al. In Norway in an epidemiological study in 2007 showed that there is a direct relationship between the magnitude of extremely low frequency electromagnetic waves above 0.4  $\mu\text{T}$  (mean weighted time) and leukemia in children. In this study, due to differences in electricity consumption in different seasons, these measurements were performed in both summer and winter seasons. In summer less than 4% of the streets surveyed showed values greater than 0.4 $\mu\text{T}$ . This increased to 29% in cold days and 34% in snowy days [48].
3. In 2006, Keikko et al measured 20 magnetic fields in 20.4 KV stations. The magnetic fields ranged from 12.3  $\mu\text{T}$  to 97.9  $\mu\text{T}$ . The discharge current was also between 350-353 A. Finally, they concluded that regular frequency contents are the main cause of the effects of contact with these fields [49].
4. In 2005, in Greece, Tsompanidou and Safigianni examined 5 indoor stations with different numerical capabilities. Measurements were carried out in a transfer room and in a room with switchboards and distribution boxes. Finally, the magnetic fields were more than 100 $\mu\text{T}$  in the 4 zones at these stations with a maximum value of 466  $\mu\text{T}$  [50].
5. In 2003, Jesus M. Paniangua, in a study in Spain, evaluated ELF contact in magnetic fields, which, after spectral analysis of these waves, revealed that the magnetic current intensity in suburban areas was higher than in residential areas [51].
6. In another study (1999), Korpenin examined several sources of ELF. He eventually produced the specified measured data for a distribution unit of 0.4 / 20, which was highest in a room that was 0.7 m above the station, which was 6.2 T. (700 Kva, load current 506 A) [52].
7. According to a study carried out by Mirtahari et al. In the parks of Tehran, it was found that the highest value was found in Parand Park, which is 14.7 V / m below the permitted level. This study highlights the intensity of these waves in several public parks, which are high-rise recreational areas and BTS towers, at an hour when traffic is high and the highest level of radiation that people may be exposed, have been measured and compared with the

ICNIRP standard [53].

## Conclusion

Experimental results show that a sleeping human being exposed to an electromagnetic field with a specific absorption rate (SAR) for 30 minutes between 1-4 W / kg will have a temperature rise of about one degree Celsius. Animal experiments also confirm this result. Exposure to a more severe field that produces a SAR exceeding 4 w / kg can disrupt the body's temperature regulation capacity and create a deleterious level of tissue heat. Experimental data and results of limited human studies make it clear that heat-stress environments and the use of drugs and alcohol can impair body temperature regulation capacity. Safety factors must be defined under these conditions to provide sufficient assurance for people exposed to these fields. Numerous laboratory studies on rodents and other mammals have shown a wide range of tissue damage for 1 to 2 degrees of temperature rise. The sensitivity of different tissues varies greatly, but the absorbance threshold is irreversible even for sensitive tissues under normal conditions above 4 W / kg. This information provides a basis for occupational radiation at 4. W / Kg, which provides sufficient safety range for specific conditions such as high ambient temperature, humidity and physical activity. Epidemiological studies on workers and people show that no major health effects are associated with routine exposure. Although there are some deficiencies in epidemiological studies, laboratory studies on cells or animals have also shown that no carcinogenic or teratogenic effects of thermal radiation from high frequency fields are observed at field intensities.

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