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| RESEARCH ARTICLE

The Side Effects of Electromagnetic Waves on Human Health: A Comprehensive Review

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| ABSTRACT
Since electromagnetic waves (EMW) have been used in various cases to treat different diseases, they can also protect stress proteins. This usage can prevent heart attacks, strengthen heart rate, reduce DNA damage, improve brain function, and prevent the growth of cancer cells. Additionally, it can cure mental disorders and strengthen the immune system when the dosage is controlled correctly. However, the radiation of electromagnetic waves (REW) can cause severe damage to both wildlife and the environment. In this research, the effects of electromagnetic waves, particularly the impact of radio waves caused by wireless telecommunications, have been studied. Electromagnetic waves pollute the environment and cause severe damage to wildlife and the ecosystem. Antennas installed between residential houses continuously emit waves that negatively affect the environment and human health in the long run. Consequently, environmental pollution caused by radio frequencies and microwaves reduces the quality of life and poses a risk to plants within 100 meters of the source.

| KEYWORDS

Radio Waves, Electromagnetic Spectrum, Ultraviolet, Frequency, Human health.

| ARTICLE INFORMATION

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1. Introduction

Electromagnetic waves are the simultaneous vibration of the electric and magnetic fields produced by the movement of charged electric particles. These waves are energy carriers consisting of a set of energy packets. Each energy packet is called a Photon (Stanizai, 2019). In electromagnetic waves, the electric and magnetic fields are perpendicular to each other in the direction of wave movement. These waves have a sinusoidal shape and do not require a material environment. Therefore, electric charge, electric field, and electric current produce a magnetic field. From the modern physics perspective (particle point of view), the nature of all electromagnetic waves is photon-related (Ahmadzai, 2015).

The movement of electrically charged particles produces electromagnetic waves. Because they produce electrically charged particles, these waves are also known as electromagnetic radiation (Stanizai, 2019). These waves pass through space, air, and other materials (X-Ray Data Booklet, 2016; X-ray Transition Energies Database, 2016). Research has shown that electromagnetic waves affect living organisms, including their growth, by changing the distribution of ions (Hyland, 2000). While the positive aspects of new technologies make people's lives easier, the adverse effects of these technologies can also harm the quality of human life. Electromagnetic waves, produced by many natural and human sources, can radiate over long distances and play an essential role in daily life (Lass, 2002). In particular, the electromagnetic fields used in RF radio frequencies for communications, radio and television, mobile phone networks, and indoor wireless systems have become an inseparable part of human life.

Especially considering the potential harm of radio waves on people, the significant increase in mobile phones has brought significant concerns for humans (Hocking, 1998, Effects of electromagnetic waves and fields on the body, 2014). The impact of mobile phone networks on human health is considered crucial because they are frequently used close to human bodies and require numerous antenna sites (Reitz, 2009). There is limited evidence of the dangers of electromagnetic waves on human health, among

which we can mention the increased risk of glioma and acoustic neuroma (cancerous tumors of the nerves and brain). In today's modern civilization, electromagnetic fields are present around all electrical devices, exposing everyone to them. Some studies show long-term exposure to amplifying antenna waves can harm health (Krameralan, 2001; Eltiti, 2007; Sadiku, 2011). Installing cell phone masts in cities can endanger people's health. The effect of the electromagnetic waves from the mobile phone BTS antenna increases according to the intensity and duration of a person's exposure to it (Huber, 2003). Electromagnetic radiation has always affected human health. In this regard, a study on the impact of mobile phone electromagnetic waves on the human brain has been conducted in the USA. The results demonstrate that the intensity of the effect rises with frequency and duration of exposure, with the former being more important than the latter (Novelline, 1997). The closer we are to the waves emitted by cell phone BTS antennas - such as antennas placed on the roof or in the yard - the more dangerous they are. The most substantial waves reach the body when the person is under the BTS antennas, but the farther we move away from the 5 km distance from the antennas, the more the waves lose their power. The effect of BTS depends on its strength and the distance of the person from it (Pirayesh, 2005).

Many researchers have studied the effects of mobile phones and magnetic field waves on human health over the last decade, and the discussion on their safety has experienced many ups and downs. The advancement of technology in the telecommunications industry and its use in different parts of life have affected human health in various ways. Among them is the mobile phone, with the effects of electromagnetic waves (EMW) caused by this communication device and mobile phone antennas divided into thermal and non-thermal effects. Laboratory research results indicate that electromagnetic waves affect brain activity by creating an electric and magnetic field and causing changes in the potential of the cell membrane and the nervous system. The main goal of this article is to study the effects of electromagnetic waves on the vital organs of the human body. Therefore, the body absorbs these waves, increasing the kinetic energy due to the increase in temperature and affecting the body's sensory organs. This article attempts to study the biochemical, biological, and physiological effects of electromagnetic waves and global reflection, fight against related pollution, and provide reasonable solutions to deal with it (Novelline, 1997; David, 1999; L'Annunziata, 2003; Denny, 1999, Sicard, 2001).

Electromagnetic field (EMF) exposure from mobile devices is associated with numerous mental and physical health effects. Studies show EMF radiation can mutate fragmented DNA, leading to cancer tumors, weakened immune systems, and genetic changes (Celik, 2004). The brain's electrical impulses and activities are impacted when exposed to EMF. Research has demonstrated that EMF exposure delays the release of melatonin and alters blood-brain barriers and post-chemical levels, which may impact memory and mental health (Lass, 2002). EMF radiation can reduce sperm count, making it more difficult for sperm to reach their destination. A study showed that EMF exposure poses a three times greater chance of miscarriage in women. EMF exposure in the womb or during the first years of life has been related to slow development, asthma, autism, obesity, and behavioral problems because a child's tissues are still developing (Nam, 2006). An estimated 20% of the population develops an acute sensitivity to EMF, causing aches, tingling, fatigue, insomnia, and many other problems when exposed to many sources of EMF radiation (Lebedeva, 2000; D'Costa, n.d; Salford, 2003).

Being under the influence of mobile phone waves while resting changes the electroencephalography and decreases the function method of the right hemisphere from 1-4 hertz. At the same time, the waves from an active mobile phone affect the functioning of the human nervous system (Rodney n.d). Excessive use of mobile phones causes people to be more exposed to dangerous electromagnetic fields. Recent research has shown that radiation from electromagnetic waves caused by mobile phones and similar devices can create symptoms such as fatigue, sleep disturbance, mild depression, misbehavior, fear, and anxiety in humans (Anuya, 2022). The human brain is one of the essential parts of the body most exposed to electromagnetic waves, posing the most significant risk to human health. Studies have shown that people exposed to different electromagnetic wave signals caused by mobile phones have suffered various harms (Heidi, n.d). Experimental research has shown that the amount of radio frequency effects of electromagnetic waves obtained in EEG studies is 76.7% while resting, 41.7% in sleep EEG, and 38.7% in behavioral studies. The new G5 technology has raised significant concerns about the adverse effects of radiofrequency electromagnetic wave fields on human health. Experimental studies on the human brain have been carried out in the last 15 years, as well as the physical mechanisms and determining factors of the dependence of the radio frequency effects of electromagnetic waves on the signal structure for a possible discovery on human health (Hiie, 2022). However, the current research is insufficient to conclude that any long-term use of mobile phones harms human health. Further research with a large sample size and accurate measurement of EMF is needed.

Cell phones are widely used by people worldwide, but more information is needed about the harms of these waves on different parts of the human body. There have been different and conflicting reports about excessive mobile phone use and exposure to these waves. This study aims to express the effects of electromagnetic waves caused by mobile phones and radio frequency devices on different parts of the human body based on the experiments and analysis of published research results. Moreover, the harms

of electromagnetic waves from mobile phones and Wi-Fi have caused many diseases. This research aims to prove the harm of electromagnetic waves caused by mobile phone waves on the human body, especially on children, the elderly, and pregnant women, and to review the various effects of mobile phone waves on human health by analyzing published research.

2. Methodology

Books and papers released before 2022 are included in this study. We investigated reliable online resources and sites like the Cochrane Library, Science Direct, ISI Web of Knowledge, Embase, and PubMed. We examined related problems using similar terms such as electromagnetic field, electromagnetic waves, radiofrequency, and shallow frequency to gain more insight into the subject. The electromagnetic fields, electromagnetic spectrum, mobile antenna, microwaves, radiation from mobile phones, radio waves, and Wi-Fi radiation have all been considered. All pertinent studies from the bibliography, reviews, and meta-analyses were retrieved, read, and examined. Initially, the articles' titles, introductions, and abstracts were read and reviewed. Subsequently, the full texts of all potentially relevant articles were obtained.

2.1 Classification of EMW

Radio Waves: Radio waves, due to their frequency, are usually used to transmit telecommunication signals, including AM, FM radio waves, and television channels (Ahmadzai, 2015; Stanizai, 2009; Huber, 2003; D'Costa, n.d).

Microwave: Microwaves are widely used for communication in mobile phones, satellite TVs, and radars. They are also used for cooking food in microwave ovens (Ahmadzai, 2015; Stanizai, 2009; Kwee, 1997; Navarro, 2003).

Infrared Waves: Infrared waves have a lower frequency than visible red light. Excessive exposure can burn the skin. They are used in remote control devices and night vision binoculars (Stanizai, 2009; Reitz, 2009).

1) Visible Region: Violet light has the highest frequency and shortest wavelength in the visible spectrum, while red light has the lowest frequency and longest wavelength (*Ahmadzai, 2015*; *Stanizai, 2009*; *Reitz, 2009*).
2) Ultraviolet: Ultraviolet waves are part of the heat radiation emitted by hot objects. About seven percent of the sun's radiation is ultraviolet, which can cause skin darkening and sunburn (*Ahmadzai, 2015*; *Stanizai, 2009*; *Reitz, 2009*).
3) X-rays: X-ray sources can be natural or artificial. Natural sources include astronomical bodies, stars, and the sun. Artificially, X-rays are created by irradiating high-energy electrons onto a metal target. These waves are used to treat some cancers and diagnose fractures. They penetrate and destroy body tissues, so frequent and unnecessary tests using X-rays should be avoided (*Ahmadzai, 2015*; *Stanizai, 2009*; *David, 1999*; X-ray Transition Energies Database, 2016; *X-Ray Data Booklet, 2009*; *Cullity, 2014*).
4) Gamma Waves: Gamma waves are the most potent type of electromagnetic wave, used in medical diagnosis and treatment. They are produced by nuclear processes such as nuclear fission, neutron stars, and black holes (*Ahmadzai, 2015*; *Stanizai, 2009*; *Reitz, 2009; Cullity, 2014*).

2.2 Electromagnetic Spectrum

Electromagnetic waves range from the frequencies of radio waves to the frequencies in the gamma wave area, as presented in Figure (1). These frequencies are related to the wavelength, with radio waves having the longest wavelength and gamma waves having the shortest. The electromagnetic spectrum spans the area between the long wavelengths of radio waves and the very short wavelengths of gamma waves, which possess the most energy in terms of energy (Stanizai, 2009).

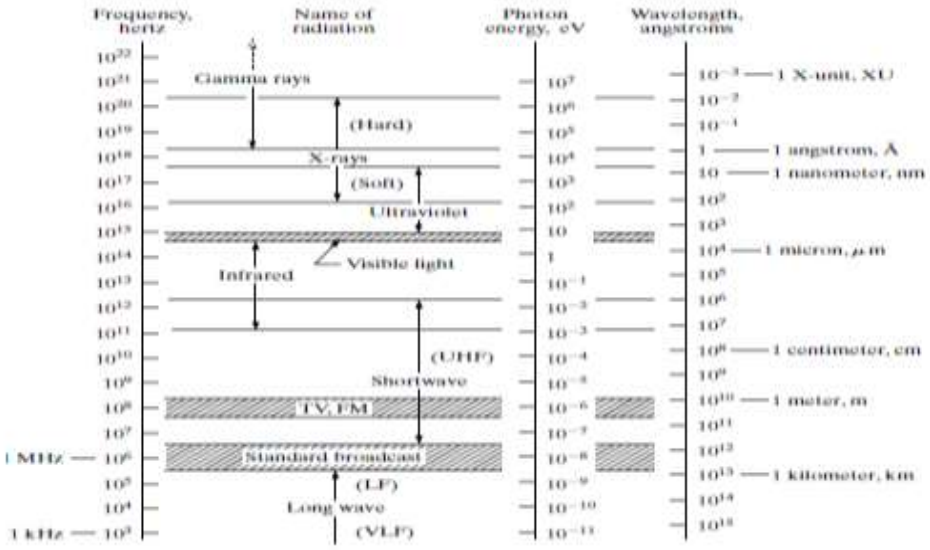

Fig. 1. The boundaries between regions of the electromagnetic spectrum are arbitrary since no sharp upper or lower limits can be assigned.

Table 1: A summary of the production, detection, and applications of the electromagnetic spectrum

Name and wavelength	**Sources**	**Detectors**	Some notable features and applications
Gamma-ray(γ) 1 pm = 10^{-12}m	Radioactive nuclei and cosmic rays	Geiger-Muller counter and photographic film	Photons with very high energy and very high penetrating power and very dangerous. Application: destroys cancerous tissues, finds cracks in metals, disinfects equipment and tools.
x-ray(x) 100pm – 10^{-10}m	X-ray lamp	Photographic film and fluorescent screen	Photons with very high energy and very high penetrating power and very dangerous. Application: Use in radiation, in the study of crystal structure, treatment of skin diseases, use in radiation therapy
Ultraviolet(UV) 10nm-10^{-8}m	Sun, very hot objects, electric sparks, vapor lamp	Photographic film and photocell	Characteristics: It is absorbed by glass, causes many chemical reactions, and eliminates living tissues. And in medicine, it has been used in UV lamps.
Visible light 0,6μm-10^{-7}m	Sun, Hot objects, lasers	Photographic film and photocell	Attributes: It plays an essential role in seeing objects, it plays a vital role in plant growth and photosynthesis, and it is

			used in the telecommunication system.
Infrared $100\mu m$-$10^{-2}m$	Sun, hot subjects	Films for photography	Features: warms the skin when absorbed. Applications: For heating, filming, and photography in the dark and light, or photography by satellites.
Radio	Microwave ovens, radio and television, and mobile phone antennas	Radio, TV, and mobile antennas	Application: in cooking, radio, television, satellite communications, and in radars to detect aircraft, missiles, and ships

(Cullity, 2014; Stanizai, 2019; *X-Ray Data Booklet, 2016*; Denny, 1999, Reitz, 2009)

2.2.1 Mobile Phone's Disadvantages for Children's Health

Research on cell phone radiation indicates that long-term use may impact the brain and contribute to brain tumor development. Since neurons produce electromagnetic waves, and the human brain also generates electromagnetic activity, the waves emitted from mobile phones can disrupt brain waves and cause issues (Nam, 2006). Additionally, the blue light emitted by mobile screens can harm children's eyes. Blue light, being part of the visible spectrum that the cornea and lens cannot effectively filter, has a particularly damaging effect on vision, especially in low-light conditions (Rezk, 2008). Among other adverse effects of mobile waves on children are increased risks of obesity, physical inactivity (Bellieni, 2008; Salford, 2003), and negative psychological impacts (34).

2.2.2 Electromagnetic Intensity Levels in Mobile Antennas

The radiation emitted by electronic devices, especially mobile phones, varies based on the power and intensity of their electromagnetic fields. National standard organizations measure the radiation from mobile antennas according to specific codes, which manufacturers must adhere to. These standards include obtaining approval certificates when entering each country to measure radiation levels. Care must be taken during installation and operation to ensure that the prescribed radiation limits are not exceeded. The Atomic Energy Organization oversees these measurements to ensure compliance, and mobile operators must also obtain certification.

Mobile phones, TVs, computers, and microwaves emit non-ionizing electromagnetic waves. The amount of radiation emitted by phones is quantified by Specific Absorption Rates (SAR). SAR indicates the maximum radiation absorbed when using phones. Higher SAR values imply greater radiation absorption. However, the actual energy emitted by mobile phones depends on signal strength. Therefore, lower SAR values suggest stronger signals requiring less energy to operate.

2.2.3 Wi-Fi Radiation Levels

The absorption of electromagnetic waves in the environment depends on material characteristics and parameters defining wave absorption. Unlike mobile phones, Wi-Fi systems typically operate at low power with a weak signal, limiting their effective range to approximately 500 meters for strong signals. It is advisable to use Wi-Fi devices only when necessary and turn them off when not in use.

Research indicates that constant exposure to Wi-Fi devices in households may negatively impact children's health, potentially affecting fertility. Placing a mobile phone close to the face resembles holding a light bulb nearby. Antennas installed near residential areas can lead to headaches, miscarriages, sleep disorders, and psychological problems (Fritze, 1997; Croft, 2002). Protecting human and environmental health involves monitoring the strength of antenna-emitted waves to mitigate potential health risks associated with excessive radiation exposure.

2.2.4 Dangers and Complications Caused by Wi-Fi

Research indicates that most Wi-Fi emissions occur during nighttime hours. During midnight, the body naturally initiates cell regeneration, detoxification processes, and energy storage for the following day. Wi-Fi waves can disrupt these processes, affecting metabolism and biological activities. For example, studies in Australia have suggested higher leukemia rates among children living near television antennas, although establishing a definitive link between proximity to antennas and leukemia is challenging due to

low incidence rates. Other research highlights various adverse effects of electromagnetic waves (EMW), including increased permeability of the blood-brain barrier, disruption of brain glucose metabolism, and damage to DNA chains. EMW exposure has also been linked to increased stress levels, disturbances in cell metabolism, elevated cancer risk, accelerated growth of brain tumors, and potential impacts on male fertility. Concerns exist regarding the vulnerability of babies' brains to radiation emitted by cell phones due to their thinner skulls (Bellieni, 2008; Nam, 2006, Effects of electromagnetic waves and fields on the body, 2014). Furthermore, numerous studies have associated mobile phone waves with cancer and various biological disorders (Kwee, 1997; Sienkiewicz, 1998; Hyland, 2000). In 2011, the World Health Organization classified these waves as carcinogenic. Leukemia and unusual headaches are among the most commonly reported health issues associated with harmful waves and radiation.

2.2.5 Radiation Dose Measurement

Natural Sources of Exposure: People are consistently exposed to natural radiation sources, although levels vary across different environments. For instance, an individual in the United States absorbs approximately three millisieverts of cosmic rays annually. Comparatively, someone in New Mexico receives about 5.1 millisieverts more radiation annually than at sea level. To put this into perspective, the amount of radiation exposure from a chest X-ray equals the cumulative exposure from the environment over about ten days.

Table 2: The amount of radiation that the human body absorbs from the environment compared to the radiation absorbed from radiology tests.

Test	The effective dose of radiation	Compared to natural radiation dose
Abdominal area		Month
Abdominal CT scan	10Msv	36
Body ST scan	10Msv	36
IVP	6.1Msv	6
Radiography: lower Gl	4 Msv	18
Radiography: upper Gl	2 Msv	8
Central nervous system		
Brain CT scan	2 Msv	8
Lung		
Lung Radiography	1 Msv	10
Lung CT scan	Msv 8	36
Children Radiography		
Voiding cystourethrogram	6.1 Msv (5 – 10 years)	6
	(infants) 8 Msv	3
Women Radiography		
Mammography	7 Msv	

(Berne, 2003, Leonard, 2003).

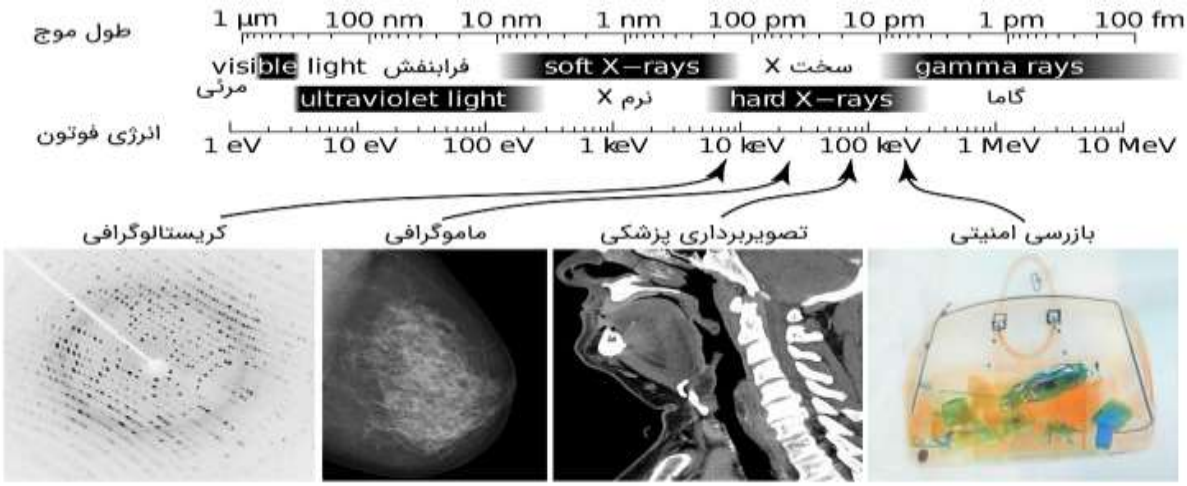

Figure 2: Electromagnetic waves play a major role in the diagnosis and treatment of diseases. However, they also have negative effects on human health, making them particularly important for detecting fractures and diagnosing diseases in the body. (Bushberg, 2002)

Effects on Children's Health: Excessive use of mobile phones among children for entertainment purposes has raised concerns about the detrimental effects of electromagnetic waves on their health. Scientific research has confirmed these dangers, highlighting that children's brain cells, due to higher moisture content, efficiently absorb radiation emitted by cell phones. Studies suggest that children habitually exposed to mobile phones, particularly when devices are present in their bedrooms and near their beds, are at increased risk of developing brain tumors during their youth. Children's smaller brain size and higher brain tissue moisture make them more vulnerable to these waves. Additional reported difficulties include increased ear and head temperatures, decreased appetite, and nausea due to elevated brain temperature and dryness. Prolonged use of mobile phones held close to the ear leads to the absorption of dangerous radiation in the brain. Ignorance among families about these harmful effects further exacerbates these health risks. Other potential health hazards associated with mobile phones and wireless devices include infertility, Alzheimer's disease, and compromised immune function. The primary danger posed by these devices is their electromagnetic radiation affecting the brain, leading to alterations in proteins and genes, which are significant contributors to global cases of silent brain damage. (Sorahan, 2004, Fritze, 1997, Croft, 2002, Parazzini, 2007, Scherlag, 2004, Wolke, 1996, Nam, 2006, Rezk, 2008).

Effects on the Cardiovascular System: The cardiovascular system, crucial for its automatic and rhythmic functioning, relies heavily on electrical currents. Disturbances in these currents, caused by exposure to electromagnetic fields, can lead to conditions such as arrhythmias, particularly among individuals with heart disease. Experimental and epidemiological studies indicate that exposure to magnetic fields affects heart rate variability and increases the risk of fatal arrhythmias. Furthermore, research has shown that electromagnetic waves can cause blood vessels to dilate or contract, elevate blood pressure, increase heart rate, induce chest pain and heart inflammation, and reduce blood flow and oxygen delivery to vital organs. (Effects of electromagnetic waves and fields on the body, 2014; Kwee, 1997; Wolke, 1996; Bellieni, 2008; Huber, 2003; Celik, 2004, Maurice, 1990, Tahvanainen, 2004)

Effects on the Brain**:** Electromagnetic waves, such as those emitted by mobile phones, are implicated in several neurological disorders, including Alzheimer's disease and Parkinson's disease, due to their impact on brain neurons. The frequencies emitted, particularly around 1 gigahertz, can disrupt magnetic materials within the brain, potentially leading to neuronal damage and brain cancer. Other reported neurological effects include disruptions to the blood-brain barrier, alterations in brain morphology, electrophysiology, neurotransmitter function, cellular metabolism, calcium flow, and altered responses to neurological medications. Symptoms associated with electromagnetic wave exposure include memory loss, impaired cognitive function, headaches, fatigue, sleep disturbances, and decreased melatonin production. These effects highlight the physiological impact of electromagnetic fields on the central nervous system and underscore their potential to induce neurological disorders. (Regel, n.d; Salih, 2015; D'Costa, n.d; Koivisto, 2000; Kwee, 1997; Lass, 2002; Lebedeva, 2000; Navarro, 2003; Salford, 2003; Hamblin, 2002; Leonard, 2003).

Electromagnetic Waves and Infertility: Experiments conducted by a group of Italian researchers on mice exposed to electromagnetic waves showed that only one-third of the ovaries in these mice developed normally, compared to 80 percent in mice not exposed to electromagnetic waves. This strengthens the hypothesis that electromagnetic waves contribute to infertility. Another group of Turkish scientists conducted experiments on male mice, revealing a decrease in sperm count due to exposure

to electromagnetic waves. This phenomenon can lead to DNA damage, oxidative stress, reduced sperm motility, adverse effects on embryo development, decreased sperm viability, and impaired fetal growth. Additionally, electromagnetic waves can damage the delicate brain tissues of babies due to the thinness of their skulls, affecting cellular tissue growth in the human body, particularly during fetal development. Pregnant women are more vulnerable to these effects, especially in the first four months of pregnancy, which can lead to reduced body cell growth and affect nerve cells. Moreover, 3G and 4G internet waves can reduce brain activity in children and women, leading to headaches, fatigue, sleep disorders, memory issues, stress, and even depression. These waves have also been associated with increased risks of abortion and complications such as premature birth, affecting fetal brain development and potentially causing hyperactivity. Wi-Fi electromagnetic waves have been linked to fetal mental retardation, behavioral problems in children, and communication issues between parents and children. Experts advise pregnant women to minimize the use of devices such as mobile phones and laptops during pregnancy, especially in Wi-Fi environments, to reduce exposure to electromagnetic waves. Risks associated with electromagnetic wave exposure during pregnancy include miscarriage, asthma, and postnatal obesity. Other potential complications include emotional and behavioral disorders, hyperactivity, thyroid issues, and memory problems in children. The impact on women's ovaries increases the risk of miscarriage and reduces melatonin production in the brain. (Pecyna, 2005; Kim, 2008; Rezk, 2008, Effects of electromagnetic waves and fields on the body, 2014).

Effects of Magnetic Fields on the Nervous System and Cells: Research indicates that various electromagnetic waves have diverse effects on the body, damaging vital molecules and impacting different parts of the nervous system and other bodily systems. These effects include the generation of heat in body tissues, leading to the destruction of molecules in excitable tissues such as nerves and muscles. This disruption disturbs normal bodily functions due to induced electric currents. Furthermore, electromagnetic waves can alter the natural magnetic fields in the brain and disrupt nerve circuitry, affecting the movement and function of vital molecules essential for brain function. (Sienkiewicz, 1998, Krameralan, 2001, Kwee, 1997, Salih, 2015, Kwee, 1997, Hyland, 2000, Regel, n.d)

3. Conclusion

This study highlights the detrimental effects of electromagnetic waves from mobile phones on human health, contributing to various diseases. Given the significant risk of cardiac arrhythmias, researchers strongly advocate keeping mobile phones away from the heart and minimizing their usage time. While this review synthesizes existing research, the original articles provide additional comprehensive insights. Studies underscore that exposure to electromagnetic waves adversely affects human sensory systems and function, yielding unfavorable outcomes. While electronic devices enhance convenience, the continuous production of new devices by researchers, companies, and manufacturers poses ongoing threats to human health, with electromagnetic fields exerting particularly high negative impacts. This article examines and analyzes various sources of electromagnetic waves, including mobile phones, Wi-Fi, microwaves, and ionizing radiation, evaluating their effects across multiple domains, from neurological and psychological systems to bone health and cartilage formation in living organisms, especially humans.

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