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Biochemical and Biomedical Implications of Non-Ionizing Electromagnetic Radiation Exposure

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ABSTRACT

Background and Objective: Non-ionizing electromagnetic radiation (NI-EMR) is a form of electromagnetic radiation that lacks the energy to ionize atoms or molecules, unlike ionizing radiation such as X-rays and gamma rays. In recent years, the widespread use of electronic devices emitting NI-EMR, such as mobile phones, Wi-Fi routers, and various wireless technologies, has raised concerns about potential health implications. This study aims to provide a detailed overview of the biochemical and biomedical implications associated with exposure to NI-EMR.

Method: A comprehensive literature search was performed using the following electronic databases: PubMed, Web of Science, Google Scholar, research gate, Academia and other journal websites. The search was conducted from inception to May 2024 with defined inclusion and exclusion criteria.

Result: The literature findings indicated that interaction between NI-EMR and biological tissues involves complex mechanisms that go beyond the traditional thermal effects associated with high-frequency ionizing radiation. Recent studies have explored the influence of NI-EMR on cellular processes, including oxidative stress, DNA damage, and alterations in signaling pathways. Oxidative stress, triggered by the production of reactive oxygen species (ROS), appears to play a central role in mediating the biological effects of NI-EMR. This oxidative stress can lead to disruptions in cellular homeostasis and potential damage to biomolecules. In the realm of biomedical implications, epidemiological studies have explored possible associations between NI-EMR exposure and adverse health outcomes, including disruptions in sleep patterns, increased stress responses, and potential links to certain chronic diseases. Understanding the underlying mechanisms and identifying vulnerable populations is crucial for developing targeted strategies to mitigate potential health risks associated with prolonged NI-EMR exposure.

Conclusion: In conclusion, this literature findings highlight the evolving landscape of research on the biochemical and biomedical implications of non-ionizing electromagnetic radiation exposure. While further investigations are necessary to establish causation and fully elucidate the mechanisms involved, the emerging evidence underscores the importance of adopting precautionary measures and promoting public awareness to minimize potential health risks associated with the omnipresence of non-ionizing electromagnetic radiation in our daily lives.

Keywords: Non-Ionizing Electromagnetic Radiation; Biochemical Effects; Biomedical Implications; EMF Exposure and Health Consequences of Non-Ionizing Radiation

Abbreviations: NI-EMR: Non-Ionizing Electromagnetic Radiation; ROS: Reactive Oxygen Species; EMFs: Electromagnetic Fields; EMR: Electromagnetic Radiation; SAR: Specific Absorption Rate; DECT: Digital Enhanced Cordless Telecommunication; HAARP: High-frequency Active Auroral Research Program; NIEMR: Non-Ionizing Electromagnetic Radiation; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; ELF-EMF: Extremely Low Frequency Electromagnetic Fields; RF: Radio Frequency; UVR: Ultraviolet Radiation; RFR: Radiofrequency Radiation

Introduction

Non-ionizing radiation refers to the flow of atomic and subatomic particles and waves that do not have enough energy to remove electrons from atoms. It includes electromagnetic waves and moving atomic particles. Dielectrics, which are materials that are not perfect, can attenuate the amplitude of electromagnetic waves and result in energy dissipation as heat in the material. Microwave and radiofrequency radiation at certain frequencies, power levels, and exposure durations can produce biological effects. Studying the biochemical and biomedical impacts of nonionizing electromagnetic radiation is important due to several reasons. Firstly, it helps in understanding the effects of electromagnetic radiation on biological cells and tissues, including thermal, non-thermal, and dielectric property changes (Biswadev, et al. [1]). This knowledge is crucial for various applications such as imaging, bio-molecular response studies, and therapeutic use (Timur, et al. [2]). Secondly, there is a need to clarify the contradictory reports and controversies surrounding the biological effects of electromagnetic fields (EMFs) (Voĭchuk [3]). Understanding the potential hazards and benefits of EMFs is essential for developing a clear conclusion on their impact on human health [4]. Additionally, studying the effects of electromagnetic radiation on genetic material and gene expression provides insights into genotoxicity and potential interactions with other entities, including chemotherapeutic compounds (Ronald, et al. [5,6]). Overall, investigating the biochemical and biomedical impacts of nonionizing electromagnetic radiation is crucial for advancing our understanding of its effects on living organisms and for exploring its potential therapeutic applications (Kudriashov, et al. [7,8]).

Exposure and Common Sources Of Exposure to Non-Ionizing Electromagnetic Radiation

Exposure to radiofrequency electromagnetic fields (EMFs) can occur through various sources such as radiofrequency wireless communication systems, millimeter-wave technologies like 5G networks, Wi-Fi devices, and IoT devices (Adel, et al. [9-14]). These sources emit non-ionizing radiation, which can have direct effects on living tissue and cause biological problems or personal symptoms. The frequencies used in wireless technology, including Wi-Fi and mobile telephony, are similar and can lead to exposure to EMFs. Common symptoms reported due to exposure to EMFs include sleep disruption, headache, lack of concentration, fatigue, and cardiovascular problems. In terms of medical devices, microwave, infrared, and visible light can also be sources of exposure, although the abstracts provided do not specifically mention these sources. It is important to continuously research and evaluate the effects of exposure to EMFs, especially with the continuous development of wireless networks and the increasing use of devices among children and adolescents. In research conducted by (Naren, et al. [12]) identified electromagnetic radiation (EMR) emitted by wireless communication modules in various Internet of Things devices as biologically hazardous to humans as well as other living beings. Different countries have different regulations to limit the radiation density levels caused by these devices. The radiation absorbed by an individual depends on various factors such as the device they use, the proximity of use, the type of antenna, the relative orientation of the antenna on the device, and many more.

Several standards exist which have tried to quantify the radiation levels and come up with safe limits of EMR absorption to prevent human harm. The radiation concern levels were determined in several scenarios using a handheld radiation meter by correlating the findings with several international standards, which are determined based on thorough scientific evidence. The EMR from common devices used in day-to-day life such as smartphones, laptops, Wi-Fi routers, hotspots, wireless earphones, smartwatches, Bluetooth speakers and other wireless accessories using a handheld radio frequency radiation measurement device were analyzed (Samaila, et al. [15,13]) reported that Societal benefits of cellular phones and wireless technology do exist, including ease and prompt access and delivery of information. The continuous radiation from most DECT cordless phone base stations and Wi-Fi routers have similar effects to exposure to cell phone. In daily life all over people are exposed to EM radiation of different frequencies having varying power. The cellular phones and telecom networks use frequencies range from 900 MHz to 2.1 GHz. The investigation Indicated that human bodies can pick up electromagnetic radiation like the antenna of a radio set. The thermal effect occurs at the surface of the head and ear, causing its temperature to increase by 10C if conversation last for 20 minutes. The most common observed biological complaints investigated are sleep disruption, headache, lack of concentration, forgetful memory, depression, fatigue, dizziness, palpitation of heart, visual disorders, and cardiovascular problem, buzzing in the head, and altered reflexes.

The behavioral difficulties in addition to bio-electromagnetic sufferings have been observed at larger scale in children. According to Specific Absorption Rate (SAR) is recommended to safely use cell phone for 18–24 minutes a day. The people living within 50–300-meter radius is in the high radiation zone and are more prone to ill-effect of EM radiation. Many studies have shown that the radiation from GSM phones breaks DNA molecules in cultured cells within 24 hours. Much of the present rise in allergies and related conditions are attributed to electromagnetic exposure releasing calcium from cell membranes. Considering EM wave's hyper sensitivity some people can "feel" the radiation because it affects their nervous systems. Many of the population are electro-sensitive but do not realize it; they have the symptoms, but because they are permanently exposed to the radiation, they regard it as "normal". Being engineers and scientists, their duty is to recommend strategies against risks to avoid health hazards. To abide safety standards there is a need to create awareness among the users, service providers and develop/publicize health based precautionary guidelines to control the damage and realize concept of health is wealth. (James [14]) noted that Mobile phones and other wireless devices and systems rely on RF or microwave radiation to function. They use RF or microwave radiation to send and receive text and voice messages, along with many other kinds of data.

In addition to RF and microwaves, millimeter and terahertz waves are increasingly enlisted to support the rally toward ubiquitous, round-the clock wireless connectivity. For the first time in its history, a ubiquitous source of RF radiation is being placed directly next to the heads (and bodies) of a large portion of the human race; in fact, the percentage of all people being exposed to RF electromagnetic radiation is rapidly approaching the percentage exposed to polluted air. the author discusses research and warnings about the health risks of human exposure to RF, microwave, and millimeter-wave electromagnetic radiation. Fabien [16] emphasized that, the impact of electromagnetic waves on health has been clearly established by many studies in recent decades. No State, with the exception of Russia, takes any real precautions in terms of standards for the population. Conflicts of interest and political lies are used to hide the truth about the dangers of electromagnetic pollution. In addition, it would seem that other sources of radiation than the most well-known ones (mobile phones, digital enhanced cordless telecommunication (DECT) phones, Bluetooth, base stations, Wi-Fi, 4G, 5G) come into play. A system such as HAARP (High-frequency Active Auroral Research Program), as well as directed wave beams (related to past and recent scandals) must be analyzed and considered in a comprehensive way to understand why the wave level is only increasing despite the considerable amount of scientific work demonstrating that the standards are not adequate to maintain public health. Thus, official documents show that the impact of electromagnetic waves is not only physical and biological. Indeed, the climate and the behavior of the population are also targeted.

Material and Method

Study Design

This systematic literature review was conducted to assess the biochemical and biomedical implications of non-ionizing electromagnetic radiation (NIEMR) exposure. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure comprehensive and transparent reporting.

Literature Search Strategy

A comprehensive literature search was performed using the following electronic databases: PubMed, Web of Science, Google Scholar, research gate, Academia and other journal websites. The search was conducted from inception to May 2024. The following keywords and Boolean operators were used: "non-ionizing electromagnetic radiation" OR "NIEMR", "Biochemical implications" OR "Biological effects", "Biomedical implications" OR "Health effects", "Exposure" AND "Systematic review"(Samaila, et al. [17]).

Inclusive and Exclusive Criteria

Studies were included if they focused on the effects of NIEMR on biochemical and biomedical parameters that Involved human, animal, or in vitro studies and published in peer-reviewed journals. The Studies published in a language other than English and articles with insufficient data were excluded (Samaila, et al. [17]).

Data Extraction and Analysis

Two independent reviewers screened the titles and abstracts of the identified studies. Full texts of potentially relevant studies were retrieved and assessed for eligibility. Discrepancies were resolved through discussion with a third reviewer. The following data were extracted from each included study: Types of research, Objective/insights, Results, Conclusions, Authors, and Year of publication. A narrative synthesis was conducted for the biochemical and biomedical outcomes of non-ionizing electromagnetic radiation exposure. Studies were grouped based on the type of outcome measured such as oxidative stress markers, DNA damage, cell viability, neurological effects, and cardiovascular effects (Samaila, et al. [17,18]).

Ethical Considerations

This systematic review did not involve any direct contact with human or animal subjects; therefore, ethical approval was not required. However, ethical considerations related to the conduct and reporting of systematic reviews were adhered to throughout the study.

Result and Discussion

The results of this study indicate that exposure to non-ionizing electromagnetic radiation can induce a variety of biochemical and biomedical changes. These changes encompass alterations in cellular metabolism, oxidative stress, and the functioning of biological molecules. Several studies suggest a potential link between NIEMR exposure and disturbances in cellular homeostasis, leading to changes in cell proliferation, apoptosis, and DNA damage. Additionally, disruptions in the endocrine system and immune response have been observed in some instances of prolonged NIEMR exposure.

Studies on the Effect of NIER on Oxidative Stress, Free Radical Formation, Cellular Metabolism and Mitochondrial Function

Exposure to non-ionizing electromagnetic radiation, such as ultraviolet rays, low-frequency alternating magnetic fields, and radiofrequency radiation, has been found to induce oxidative stress and free radical formation in various studies (Anton, et al. [2,4,19,20]). These effects can lead to an increase in lipid peroxidation products and a decrease in antioxidant components, resulting in an imbalance in the antioxidant defense system. Non-ionizing radiation can cause changes in cell membrane structure and function, genetic effects, and extracellular/intracellular signaling pathways, all of which contribute to oxidative stress. Additionally, exposure to electromagnetic fields (EMFs) has been shown to induce apoptosis, DNA strand-breaks, and oxidative damage in cells. The impact of oxidative stress caused by EMF exposure has been observed in various tissues of the body, and it can impair cellular functions and contribute to the development of cancer. Extremely low frequency electromagnetic fields (ELF-EMF), has been shown to have an impact on cellular metabolism and mitochondrial function. Studies have demonstrated that long-term exposure to ELF-EMF can reduce the proliferation of cancer cells and

increase mitochondrial activity without affecting ATP levels (Dietrich [21]) as in Table 1. Additionally, it has been found that ELF-EMF exposure can modulate the expression of mitochondrial proteins and their levels within the organelle (Burlaka, et al. [22]). Furthermore, research suggests that the effects of electromagnetic radiation on cellular metabolism and mitochondrial function may be mediated through the generation of superoxide radicals and nitric oxide in the electron transport chain of brain cell mitochondria (Michele, et al.[23]).

Table 1: An overview of the literature findings on the effects of NIER on oxidative stress, free radical formation, cellular metabolism and mitochondrial function.

Types of Research	Objective/Insights	Results	Conclusions	References
Substantiation of the choice of the model for the formation of oxidative stress in preclinical studies	To compare different models of oxidative stress induction, including exposure to a low-frequency alternating magnetic field	Exposure to ultraviolet rays induces increase in lipid peroxidation and decrease in antioxidant activity in rats. Cold exposure in rats leads to more pronounced prooxidant effect	The results indicated that ultraviolet radiation on rats was the most effective model.	Anton, et al. [4]
Oxidative Stress as the Underlying Biomechanism of Detrimental Outcomes of Ionizing and Non-Ionizing Radiation on Human Health: Antioxidant Protective Strategies	To investigate exposure to non-ionizing electromagnetic radiation, such as radiofrequency fields from mobile phones that can lead to oxidative stress and the formation of free radicals	The findings showed that exposure to ionizing and non-ionizing radiations activates oxidizing events and Oxidative stress causes impairment of cell functions	Oxidative stress plays a significant role in the detrimental effects of radiation on human health. - Exposure to ionizing and non-ionizing radiations can activate oxidizing events, causing damage to macromolecules.	Abolfaz, et al. [19]
Effects of electromagnetic fields exposure on the antioxidant defense system	The purpose of this study was to highlight the impact of oxidative stress on antioxidant systems	Exposure to electromagnetic fields (EMF) results in oxidative stress in many tissues of the body. EMF exposure increases free radical concentrations and traceability.	EMF exposure leads to oxidative stress - Antioxidant defense systems are impacted by EMF exposure	Elfide, et al. [20]
When theory and observation collide: Can non-ionizing radiation cause cancer?	Studies have shown that exposure to non-ionizing radiation can lead to oxidative stress and the formation of free radicals, which can contribute to adverse health effects, including cancer.	The findings indicated that NIR interferes with oxidative repair mechanisms, leading to cancer	Non-ionizing radiation (NIR) can cause cancer and existing guidelines on NIR safety need to be reexamined	Magda [34]
Radiation and oxidative stress	The provided text does not mention studies specifically on oxidative stress and free radical formation due to exposure to non-ionizing electromagnetic radiation	Radiation causes oxidative stress in living organisms. - There is a relationship between oxidative stress and radiation.	There is a need to measure oxidative stress parameters in medicine	Ural [53]
Oxidative stress and low dose ionizing radiation	To examine Oxidative stress and low dose ionizing radiation	Radiographers showed increased susceptibility to RBC hemolysis. Malondialdehyde and catalase levels slightly increased in radiographers	Radiographers have increased susceptibility to RBC hemolysis. Exposure to low dose ionizing radiation causes oxidative stress	Shilpa, et al. [52]
Low intensity radiofrequency radiation: a new oxidant for living cells		The findings showed that Low intensity RFR exposure can cause overproduction of ROS in living cells and Increased levels of ROS can lead to mutagenic effects and various health disorders.	The result has shown that exposure to low intensity non-ionizing electromagnetic radiation can induce oxidative stress and increase free radical formation in living cells.	Igor, et al. [48]
Electromagnetic Fields and Free Radicals	Investigation of free radical formation and effects in living cells	The findings suggest exposure to non-ionizing electromagnetic fields may increase oxidative potential and free radical burden in cells.	EMFs may increase oxidative potential and free radical burden in cells. - EMF-induced loss of iron from ferritin may increase oxidative stress	Richard [50]

Manmade Electromagnetic Fields and Oxidative Stress-Biological Effects and Consequences for Health.	To examine Manmade Electromagnetic Fields and Oxidative Stress-Biological Effects and Consequences for Health	Findings shown that exposure to non-ionizing electromagnetic radiation can lead to increased oxidative stress and free radical formation in animals and cells.	EMF exposure can lead to oxidative stress - Animal and cell studies show increased oxidative stress. However, there is need for human studies and epidemiological studies.	David, et al. [43]
Role of Mitochondria in Radiation Responses: Epigenetic, Metabolic, and Signaling Impacts	Focused on how energy, dose and quality of ionizing radiation (IR) affect mitochondria-dependent epigenetic and functional control at the cellular and tissue level	Low-dose radiation affects mitochondria through epigenetic and non-targeted effects, while high-dose radiation affects therapeutic outcomes and immune responses	Mitochondria play a pivotal role in radiation responses. Low-dose radiation affects mitochondria and associated genomic instability	Dietrich, et al. [21]
Disordered redox metabolism of brain cells in rats exposed to low doses of ionizing radiation or UHF electromagnetic radiation.	The study investigates the effects of non-ionizing electromagnetic radiation on cellular metabolism and mitochondrial function, finding changes in redox-state and increased generation of superoxide radicals and nitric oxide.	The detected changes in the electron transport chain of mitochondria of brain cells upon low-intensity irradiation or UHF EMR cause the metabolic reprogramming of cell mitochondria that increases the rate of superoxide radical generation and nitric oxide, which may initiate the development of neurodegenerative diseases and cancer.	Changes in redox-state of brain cells can initiate neurodegenerative diseases and cancer. Exposure to ionizing radiation or UHF EMR increases superoxide radical generation and nitric oxide in brain cells	Burlaka, et al. [22]
Extremely low frequency electromagnetic fields affect proliferation and mitochondrial activity of human cancer cell lines	To investigate the effects of Extremely low frequency electromagnetic fields on proliferation and mitochondrial activity of human cancer cell lines	The results of the study indicate that ELF-EMF can negatively modulate cancer cell growth increasing respiratory activity of cells and altering mitochondrial protein expression.	ELF-EMF affects cancer cell proliferation through mitochondrial activity modulation. Increased respiratory chain activity hinders tumor growth	Michele, et al. [23]
Genetic effects of non-ionizing electromagnetic fields	To examine the Genetic effects of non-ionizing electromagnetic fields	EMF causes genetic damages in cells and animals. - EMF can interact synergistically with other entities	EMF causes genetic damages in living organisms and interact synergistically with other entities	Henry [6]
Research progress in effect of electromagnetic radiation on mitochondrial function	To understand the biological effects of electromagnetic radiation, including its impact on mitochondrial function	The findings indicates that Mitochondria are involved in the biological effects of electromagnetic radiation	Electromagnetic radiation has biological effects on organisms	Chunmei [24]
Targeting of cellular redox metabolism for mitigation of radiation injury	To investigate the impact of non-ionizing electromagnetic radiation on cellular metabolism and mitochondrial function	Radiation exposure disrupts cellular redox metabolism. Modulation of cellular metabolism can mitigate radiation injury	Radiation exposure disrupts cellular redox metabolism and increases metabolism can mitigate radiation injury	Bagher, et al. [40]
Mechanisms of Energy Metabolism in Skeletal Muscle Mitochondria Following Radiation Exposure	To examine Mechanisms of Energy Metabolism in Skeletal Muscle Mitochondria Following Radiation Exposure	It is shown that ionizing radiation increased mitochondrial protein and mass and enhanced proton leak and mitochondrial maximal respiratory capacity, causing an increase in the fraction of mitochondrial respiration devoted to uncoupling reactions, and that alterations in mitochondrial mass and function are important adaptive responses of skeletal muscle to radiation.	Radiation exposure increases mitochondrial protein and mass. Radiation-induced alterations in mitochondrial energy metabolism involve adenosine monophosphate-activated kinase signaling.	Eun-Ju, et al. [45]
Biological effects of non-ionizing electromagnetic fields: Two sides of a coin	To discuss the effects of non-ionizing electromagnetic fields on cells and organs, including the induction of oxidative stress and DNA damage	The findings Highlighted the therapeutic potential of EMFs for clinical use	EMFs have both beneficial and adverse effects - EMFs have therapeutic potential for clinical use	Timur, et al. [2]

Ionizing radiation-induced metabolic oxidative stress and prolonged cell injury	The research focuses on the impact of ionizing radiation on cellular metabolism and mitochondrial function, not non-ionizing electromagnetic radiation.	Ionizing radiation leads to oxidative stress and cell injury. Mitochondrial dysfunction contributes to long-term effects	Mitochondrial dysfunction contributes to long-term effects	Edouard, et al. [44]
Cytoplasmic irradiation results in mitochondrial dysfunction and DRP1-dependent mitochondrial fission	Analysis of Cytoplasmic irradiation results in mitochondrial dysfunction and DRP1	Cytoplasmic irradiation leads to mitochondrial fragmentation and dysfunction. - Increased expression of DRP1 promotes mitochondrial fission.	The results showed that Inhibition of DRP1 prevents radiation-induced mitochondrial fission.	Bo, et al. [41]

These changes in mitochondrial function can lead to metabolic reprogramming and potentially contribute to the development of neurodegenerative diseases and cancer (Henry [6]). The impact of non-ionizing electromagnetic radiation on cellular metabolism and mitochondrial function is an area of ongoing research with potential implications for human health (Chunmei [24]). NIR can also induce oxidative stress, which is a condition in which there is an imbalance between the production of free radicals and the body's ability to detoxify them. Oxidative stress can damage cells and DNA, and it has been linked to a number of health problems, including cancer, heart disease, and neurodegenerative diseases. A study by Priyadarsini, et al. [25]) and (Adey, et al. [26]) found that exposure to radiofrequency EMFs caused oxidative stress in rat brain cells. This can lead to a variety of effects, including changes in cell growth, differentiation, and apoptosis (programmed cell death). A study by (Singh, et al. [27]) found that exposure to microwave EMFs caused changes in cell signaling pathways in rat brain cells. NIR can also alter gene expression, which is the process by which genes are turned on and off. This can lead to changes in the production of proteins, which can have a wide range of effects on cell function. A study by (Zhang, et al. [28]) found that exposure to radiofrequency EMFs caused changes in gene expression in rat brain cells. NIR can increase the production of ROS, which are molecules that can damage cells and DNA. This can lead to a variety of health problems, including cancer, inflammation, and premature aging.

It can also alter gene expression, which is the process by which genes are turned on and off. This can lead to changes in cell function and metabolism (Lahir, [29,30]). NIR can also affect cellular signaling pathways, which are the networks of molecules that cells use to communicate with each other. This can lead to changes in cell growth, differentiation, and death (Sivakumar [31]). NIR can modulate the immune system, which is the body's defense system against disease. This can be beneficial in some cases, such as the treatment of cancer, but it can also be harmful in others, such as the development of autoimmune diseases. NIR affect brain function, including learning, memory, and mood. This is thought to be due to the effects of NIR on gene expression and cellular signaling pathways in the brain (Singh [26,32]). It is important to note that the effects of NIR on the body can vary depending on a number of factors, including the frequency, intensity, and duration of exposure, as well as the individual's sensitivity to NIR. More research is needed to fully understand the risks and benefits of NIR exposure.

DNA Damage and Repair Mechanisms

Non-ionizing electromagnetic radiation exposure has been shown to cause DNA damage. Studies have documented evidence of free-radical damage in both extremely low frequency (ELF) electromagnetic fields (EMF) and radio frequency (RF) radiation, which are non-ionizing (Timur, et al. [2]). This damage occurs through interference with oxidative repair mechanisms, resulting in oxidative stress, damage to cellular components including DNA, and disruption of cellular processes that can lead to mutations in the genetic code and the development of cancer (Vaishali, et al. [33]). Additionally, exposure to non-ionizing radiation such as ultraviolet radiation (UVR) has been found to damage DNA and cause genetic mutations (Magda [34]). Furthermore, the detrimental effects of ionizing radiation, which is known to cause DNA damage, have been observed not only in directly irradiated cells but also in non-irradiated bystander or distant cells (Omar, et al. [35]). Therefore, non-ionizing electromagnetic radiation exposure can indeed cause DNA damage (Yeung, et al. [36]). However, it is known that exposure to non-ionizing radiation can affect the efficiency of DNA repair. Further research is needed to understand how epigenetic modifications and other factors interact with the DNA repair machinery in the presence of non-ionizing radiation.

Thermal Effects of NIER Exposure

In the year 1980, Foster and Schwan conducted another research published in the journal IEEE Transactions on Microwave Theory and Techniques on microwaves. The findings of the research indicated that exposure to high levels of microwaves can cause burns in humans. (Okano, et al. [37]) found that exposure to high levels of radiofrequency radiation (RFR) can cause cataracts in mice. In a similar study conducted by (Michaelson, et al. [38]) found that exposure to RFR can increase the body temperature of rats.

Conclusion

The literature findings have generated significant insights into the potential effects of non-ionizing electromagnetic radiation exposure [39-45]. The non-ionizing electromagnetic radiation does not

possess sufficient energy to ionize atoms and molecules, emerging evidence suggests that prolonged exposure may still elicit biological responses. The available evidence indicates that non-ionizing electromagnetic radiation, such as that emitted by mobile phones, Wi-Fi devices, and other wireless technologies, generally does not possess enough energy to cause direct ionization of cellular components. However, it can induce biological responses at the molecular and cellular levels through mechanisms such as thermal effects, oxidative stress, and modulation of cellular signaling pathways [46-50]. On one hand, some studies have reported potential links between long-term exposure to non-ionizing radiation and adverse health effects, including changes in sleep patterns, increased oxidative stress, and alterations in reproductive parameters. It is crucial to note that the majority of studies conducted so far have limitations, including variations in study design, exposure assessment methods, and outcome measures. Additionally, the rapid evolution of technology and the continuous increase in the use of wireless devices pose challenges for researchers to keep pace with assessing potential long-term health effects [51-53]. In light of these uncertainties, precautionary measures and continued research efforts are warranted. Regulatory bodies should regularly review exposure guidelines to ensure they reflect the latest scientific understanding and advancements in technology. Furthermore, promoting public awareness and education about prudent use of electronic devices and adopting safety measures can contribute to minimizing potential risks associated with non-ionizing electromagnetic radiation.

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