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Assessing the impact of radiofrequency radiation from cellular towers on human health: A comprehensive review

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Abstract

The proliferation of cellular communication towers, driven by the rapid advancement of wireless technologies like 4G and 5G, has raised significant public health concerns regarding the potential effects of long-term exposure to radiofrequency (RF) electromagnetic radiation (EMR). This review explores the implications of RF radiation emitted by these towers, which is classified as non-ionizing and typically associated with thermal effects, albeit at levels considered safe by major health organizations such as the World Health Organization (WHO) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Key topics addressed include the mechanisms of RF radiation interaction with biological systems, public concerns about health effects including cancer risks, neurological impacts, reproductive health, and the controversial condition known as electromagnetic hypersensitivity (EHS). While numerous studies suggest that RF exposure does not lead to significant adverse health outcomes at permissible levels, evidence regarding potential non-thermal effects, such as oxidative stress and changes in cell signaling, remains inconclusive. The review emphasizes the need for further research into the long-term effects of RF radiation, particularly with the expansion of 5G technology, and considers the regulatory frameworks established to ensure public safety. The conclusion highlights a cautious approach, advocating for ongoing scientific inquiry and the application of the precautionary principle, especially concerning vulnerable populations like children and pregnant women.

Keywords: Cellular communication towers; Radiofrequency electromagnetic radiation; Non-ionizing radiation; 4G and 5G technologies; Public health concerns; Safety guidelines

1. Introduction

Cellular communication towers, also referred to as base stations, transmit radiofrequency (RF) electromagnetic radiation (EMR) to facilitate wireless communication systems such as mobile phones, broadband internet, and other wireless technologies. The increasing reliance on these technologies, especially with the advent of 4G and 5G networks, has led to a dramatic rise in the number of base stations worldwide. As a result, public concerns have intensified regarding the potential health effects of chronic, long-term exposure to low-intensity RF radiation from these towers. The critical issue under debate is whether non-ionizing radiation, such as RF emissions, poses a risk to human health when exposure is sustained over extended periods.

1.1. Overview of Radiofrequency Electromagnetic Radiation

RF radiation is part of the non-ionizing portion of the electromagnetic spectrum, which means it does not have sufficient energy to ionize atoms or molecules, in contrast to ionizing radiation like X-rays and gamma rays (Repacholi et al., 2001). Non-ionizing radiation is primarily associated with thermal effects, where energy from radiation is absorbed by

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tissue and results in heating. However, at the low intensities emitted by cell towers, these thermal effects are generally considered negligible (Foster & Moulder, 2013).

4G and 5G networks differ in terms of the frequency bands they operate on. While 4G operates in lower frequency ranges (typically between 700 MHz and 2.6 GHz), 5G utilizes a broader spectrum, including millimeter waves (up to 60 GHz). This raises additional concerns because higher frequency waves can penetrate biological tissues differently, though their overall energy absorption remains lower compared to ionizing radiation (Simko & Mattsson, 2019).

1.2. Public Concerns and Scientific Inquiry

The deployment of 5G and the increasing density of cell towers, particularly in urban areas, have sparked significant public debate. Electromagnetic hypersensitivity (EHS), concerns about cancer risks, and effects on neurological functions have been among the primary health-related issues raised by communities living near base stations (Khurana et al., 2010). This has driven both public interest and scientific research to investigate whether low-intensity RF radiation poses biological risks, especially in terms of long-term exposure.

While health organizations such as the World Health Organization (WHO), International Commission on Non-Ionizing Radiation Protection (ICNIRP), and Federal Communications Commission (FCC) maintain that exposure levels from mobile towers are within safe limits, some studies suggest that non-thermal biological effects could occur. These non-thermal effects include the generation of oxidative stress, changes in cell signaling pathways, and potential impacts on reproductive and neurological health (Pall, 2018).

The overarching research question is whether these non-ionizing RF emissions, particularly over long durations, can lead to adverse health outcomes. While acute high-intensity exposures have been shown to cause thermal damage, the chronic effects of low-intensity RF exposure are less clear. There is an ongoing need for research that explores potential long-term effects, especially as 5G networks are rapidly expanding (Russell, 2018).

1.3. Mechanism of Radiation and Biological Interaction

Tower radiation (radiofrequency radiation from cellular base stations) is categorized as non-ionizing radiation, meaning it lacks sufficient energy to remove tightly bound electrons or directly break chemical bonds in biological molecules. Unlike ionizing radiation (e.g., X-rays, gamma rays), non-ionizing radiation, such as radiofrequency (RF) radiation, does not ionize atoms or molecules. However, non-ionizing radiation can still induce biological effects, particularly through thermal and non-thermal mechanisms.

1.3.1. Thermal Effects

Thermal effects occur when RF radiation is absorbed by biological tissues and converted into heat. This heat can cause a rise in tissue temperature, potentially leading to thermal damage at very high exposure levels. The Specific Absorption Rate (SAR) is the metric commonly used to measure the rate at which RF energy is absorbed by body tissues. RF radiation from sources like mobile phones and cell towers can produce thermal effects, but these are typically minimal at the low levels of radiation emitted by cell towers (Repacholi et al., 2001). SAR thresholds established by regulatory bodies, such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP), ensure that the thermal impact of RF radiation remains well within safe limits (ICNIRP, 2020).

RF radiation can cause tissue heating when exposure exceeds certain thresholds. However, the low power density of radiation emitted by cellular towers is far below these thresholds, making thermal damage unlikely under typical exposure conditions (Foster & Moulder, 2013).

1.3.2. Non-Thermal Effects

Non-thermal effects refer to biological responses that are not due to tissue heating. While thermal effects are well understood, the non-thermal effects of RF radiation remain a subject of debate. Some studies propose that RF radiation might trigger cellular stress responses and alter cell membrane permeability, which can lead to oxidative stress and other biological effects, even at low-intensity exposure levels. However, evidence for these non-thermal effects is not conclusive, and no established mechanism has been definitively proven (Belyaev, 2015).

Key proposed mechanisms for non-thermal effects include:

- **Oxidative Stress**: RF radiation has been suggested to induce the production of reactive oxygen species (ROS), leading to oxidative damage within cells. ROS are chemically reactive molecules that can damage cellular

components, such as DNA, lipids, and proteins, and are associated with aging and various diseases, including cancer (Yakymenko et al., 2010). Some studies indicate an increase in oxidative stress markers following exposure to low-level RF radiation, though these results are not universally replicated (Desai et al., 2009).

- **Cell Membrane Permeability**: There is evidence that RF radiation may affect the structure and function of cell membranes, leading to changes in permeability. Altered membrane permeability can disrupt ion exchange and other critical cell functions, which could trigger downstream biological effects. Research on this topic is ongoing, but current data are inconclusive (Panagopoulos, 2019).
- **Cellular Stress Responses**: Some research has indicated that RF radiation can activate cellular stress pathways, such as the heat shock protein (HSP) response. HSPs are molecular chaperones that help protect cells from damage caused by environmental stressors, including heat and radiation. The activation of HSPs in response to non-ionizing radiation, however, is typically associated with much higher levels of exposure than those emitted by cell towers (Leszczynski, 2014).
- **Impact on DNA and Genetic Material**: There is limited evidence suggesting that RF radiation might induce genotoxic effects (i.e., damage to genetic material). Some studies have reported increased rates of DNA damage and micronuclei formation after RF exposure, but these findings are inconsistent and require further investigation to determine their relevance to low-level, long-term exposure (Mišík et al., 2023).

2. Health Effects of Tower Radiation on Humans

2.1. Cancer Risk

The potential association between exposure to radiofrequency (RF) radiation from cellular towers and cancer risk has been one of the most controversial topics in public health research. Epidemiological studies investigating this link have yielded mixed results, with some studies suggesting an increased risk of cancer for those living near cell towers, while others have found no such association.

- **Leukemia and Brain Cancer**: A few studies have reported a potential increase in cancers such as leukemia and brain cancer among individuals living close to mobile phone towers (Khurana et al., 2010). For instance, a German study found that individuals living within 400 meters of a cell tower had a higher incidence of cancer after 10 years of exposure (Eger et al., 2006). However, the evidence is not consistent, and other studies have failed to replicate these findings (Elwood, 1999).
- **IARC Classification**: In 2011, the International Agency for Research on Cancer (IARC), part of the World Health Organization (WHO), classified RF radiation as "possibly carcinogenic to humans" (Group 2B). This classification indicates that there is limited evidence of carcinogenicity in humans and experimental animals but insufficient evidence to draw firm conclusions (Baan et al., 2011).
- **Large-Scale Reviews**: Several large-scale reviews, including those by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Health Canada, have concluded that there is no clear evidence to suggest that RF radiation from cell towers at current exposure levels causes cancer (Foster & Moulder, 2013). These reviews generally argue that while the evidence warrants caution, the power density of radiation from towers is far below the levels shown to cause biological damage.

2.2. Neurological and Cognitive Effects

There is growing interest in how RF radiation may affect neurological health, particularly concerning sleep and cognitive function. Several studies have explored the potential impact of non-ionizing radiation on the brain and nervous system.

- **Sleep Disorders**: Some epidemiological studies have suggested that exposure to RF radiation from cell towers may increase the prevalence of sleep disturbances such as insomnia and reduced sleep quality (Levitt & Lai, 2010). For example, one study in Austria found that individuals living near mobile phone base stations reported more frequent symptoms of insomnia and headaches (Hutter et al., 2006). However, these findings are not consistent across all research, and other studies have found no significant link between tower proximity and sleep issues (Mohler et al., 2010).
- **Cognitive Function**: There is limited and inconsistent evidence that long-term exposure to low-level RF radiation could affect cognitive function, particularly memory and attention. Some studies have suggested that prolonged exposure might lead to reduced cognitive performance, though these effects are often subtle and difficult to quantify. Experimental studies in animals have found alterations in neurotransmitter levels and behavioral changes after RF exposure, but human studies have not consistently supported these findings (Loughran et al., 2019).

2.3. Reproductive and Developmental Effects

Concerns about the possible effects of RF radiation on reproductive health and development have led to numerous studies, particularly focusing on male fertility and embryonic development.

- **Animal Studies**: Research on animals has shown that exposure to high levels of RF radiation can negatively affect sperm quality, motility, and embryonic development (Kesari et al., 2011). For example, studies on rats exposed to RF radiation have reported a decrease in sperm count and quality, as well as damage to sperm DNA (Agarwal et al., 2009). However, these studies often involve radiation levels far higher than those emitted by cell towers.
- **Human Studies**: In contrast, human studies have not found conclusive evidence of reproductive harm from exposure to RF radiation at the levels typically emitted by cell towers. A review of the literature concluded that there is no strong evidence to suggest that living near a cell tower or being exposed to environmental RF radiation at safety-compliant levels has significant adverse effects on fertility or pregnancy outcomes (Schoeni et al., 2015).

2.4. Electromagnetic Hypersensitivity (EHS)

Electromagnetic Hypersensitivity is a condition in which individuals report symptoms such as headaches, fatigue, dizziness, and cognitive disturbances when exposed to electromagnetic fields (EMFs), including those from RF radiation. Despite numerous reports of these symptoms, research has struggled to find a biological mechanism linking exposure to tower radiation with EHS.

- **Symptoms and Psychosomatic Factors**: Studies on EHS have found that while the symptoms experienced by individuals are real, there is little evidence to suggest that these symptoms are caused by RF radiation exposure. In double-blind studies, individuals who reported EHS were unable to reliably distinguish between active RF exposure and sham exposure, suggesting that psychological factors may play a role in the condition (Rubin et al., 2005).
- **Ongoing Debate**: The debate over EHS continues, with some researchers arguing that the condition is psychosomatic and may result from a nocebo effect (where the expectation of harm causes the symptoms), while others suggest that further investigation is needed into potential non-thermal effects that could be triggering symptoms in sensitive individuals (Dieudonné, 2020).

3. Safety Guidelines and Regulatory Standards for RF Radiation

To protect public health from the potential risks of radiofrequency (RF) radiation, various international and national agencies have developed safety guidelines and regulatory standards. These guidelines establish exposure limits based on current scientific understanding, primarily focused on the thermal effects of RF radiation, which refer to the heating of biological tissues due to energy absorption.

3.1. International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guidelines

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is one of the leading organizations responsible for establishing global safety standards for exposure to RF radiation. Its guidelines, updated in 2020, define specific absorption rate (SAR) limits and power density thresholds for public and occupational exposure.

- **SAR Limits**: The specific absorption rate (SAR) is a measure of the rate at which the body absorbs RF energy. ICNIRP sets a SAR limit of 2 W/kg averaged over 10 grams of tissue for the general public and 10 W/kg for occupational exposure (ICNIRP, 2020). These limits are designed to prevent thermal damage from excessive RF radiation.
- **Power Density**: ICNIRP's guidelines also establish power density limits for higher frequency bands (up to 300 GHz) used in modern wireless communication, including 5G. For frequencies above 6 GHz, the ICNIRP limits exposure to 10 W/m^2 averaged over 6 minutes for general public exposure and 50 W/m^2 for occupational exposure (ICNIRP, 2020). These limits are based on preventing significant tissue heating and ensuring a margin of safety.

The ICNIRP guidelines are based on comprehensive reviews of scientific research, focusing on thermal effects but also acknowledging the need for continued research into non-thermal effects. The guidelines emphasize that current exposure limits are well below the levels where harmful thermal effects could occur, providing a substantial safety margin to protect public health (Vecchia et al., 2011).

3.2. Federal Communications Commission (FCC) Standards

In the United States, the Federal Communications Commission (FCC) regulates RF radiation exposure from communication devices and infrastructure, including cell towers. The FCC's RF exposure limits are based on recommendations from both the National Council on Radiation Protection and Measurements (NCRP) and the Institute of Electrical and Electronics Engineers (IEEE).

- **Public and Occupational Exposure Limits**: The FCC sets separate RF exposure limits for the general public and for occupational settings. For frequencies between 30 MHz and 300 GHz, the maximum permissible exposure (MPE) for the general public is 1 mW/cm^2, while the occupational limit is 5 mW/cm^2, averaged over any 30-minute period (Fields, 1997). These limits are consistent with those established by ICNIRP and are designed to prevent harmful thermal effects.
- **Exposure Assessment**: The FCC requires telecommunications companies to ensure that RF emissions from devices and infrastructure remain within these exposure limits. Compliance is assessed using methods such as computer modeling, field measurements, and SAR testing of devices like mobile phones (Fields, 1997).

3.3. World Health Organization (WHO) and International Agency for Research on Cancer (IARC) Perspectives

The World Health Organization (WHO), in collaboration with the International Agency for Research on Cancer (IARC), has evaluated the potential health risks of RF radiation. In 2011, the IARC classified RF radiation as "possibly carcinogenic to humans" (Group 2B), based on limited evidence for an increased risk of glioma (a type of brain cancer) from mobile phone use (Baan et al., 2011). However, the IARC emphasized that more research is needed, especially concerning long-term, low-level exposure from sources such as cell towers.

The WHO continues to review emerging evidence related to non-thermal effects of RF radiation, including potential links to cancer and other health issues, but currently states that there is no conclusive evidence to suggest that exposure to RF radiation within ICNIRP or FCC guidelines poses a significant health risk (WHO, 2011).

3.4. 5G Technology and Evolving Guidelines

The rollout of 5G networks has raised new concerns about RF exposure, as this technology operates at higher frequency bands (above 6 GHz) than previous generations of wireless communication. These higher frequencies are still within the non-ionizing portion of the electromagnetic spectrum, but they have prompted renewed scrutiny of existing safety standards.

- **Millimeter Waves**: 5G uses millimeter-wave frequencies (30–300 GHz), which are absorbed primarily in the outer layers of the skin and do not penetrate as deeply into tissues as lower frequency waves. This raises questions about whether existing SAR and power density limits are appropriate for these higher frequencies, and whether additional research is needed to assess long-term exposure effects (Frank, 2021).
- **Regulatory Response**: Both the ICNIRP and FCC have extended their existing guidelines to cover the frequency bands used by 5G. These guidelines account for the different absorption characteristics of higher-frequency RF radiation and continue to be based primarily on preventing thermal effects. Some researchers, however, argue that additional studies are necessary to fully understand the potential non-thermal biological effects of 5G technology (Russell, 2018).

3.5. Criticisms and Ongoing Research

Despite the established safety guidelines, some researchers and public health advocates argue that current standards may not adequately account for long-term exposure and non-thermal biological effects. They call for more stringent regulations and additional research on the health impacts of chronic, low-level RF exposure, particularly from 5G networks (Cucurachi et al., 2013).

- **Non-Thermal Effects**: While most regulatory standards focus on preventing thermal effects, there is ongoing research into potential non-thermal effects of RF radiation, such as oxidative stress, DNA damage, and impacts on the nervous system. However, to date, the scientific community has not reached a consensus on whether non-thermal effects occur at exposure levels below current safety limits (Miller et al., 2019).

4. Discussion on the Health Impacts of Cell Tower Radiation

The increasing deployment of cell towers to support expanding mobile networks, particularly with the advent of 5G, has raised public health concerns about potential long-term effects of radiofrequency (RF) electromagnetic radiation (EMR). Scientific research on this topic has produced mixed results, with many studies suggesting that RF radiation emitted by cell towers, within current safety guidelines, does not lead to significant adverse health outcomes such as cancer or neurological disorders. However, uncertainties remain, especially regarding non-thermal biological effects and the long-term implications of cumulative exposure.

4.1. Lack of Conclusive Evidence on Severe Health Effects

The majority of studies do not show a clear link between RF radiation exposure from cell towers and severe health effects such as cancer or neurological disorders. Multiple large-scale reviews and meta-analyses by reputable bodies like the World Health Organization (WHO) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) have concluded that non-ionizing RF radiation, at levels below current exposure limits, is unlikely to pose significant health risks to the general public (Vecchia et al., 2011; WHO, 2011).

- **Cancer Risk**: While some epidemiological studies have hinted at a possible association between living near cell towers and an increased risk of cancers such as brain tumors or leukemia, these studies often suffer from methodological limitations such as small sample sizes and potential confounding factors (Hardell & Carlberg, 2015). The International Agency for Research on Cancer (IARC) classified RF radiation as "possibly carcinogenic" (Group 2B) in 2011 based on limited evidence, but it emphasized that this classification does not equate to a definitive risk (Baan et al., 2011). More research is needed to assess any potential carcinogenic effects over long-term, low-level exposure from sources like cell towers.
- **Neurological Effects**: Studies investigating the effects of RF radiation on the brain and central nervous system have similarly produced inconsistent results. Some researchers have reported sleep disturbances, memory problems, and headaches among people living near cell towers (Hutter et al., 2006), while others have found no significant association between RF exposure and cognitive or neurological impairments (Smythe & Costall, 2003). The current consensus is that acute exposure to RF radiation from cell towers is unlikely to cause neurological damage, but the long-term effects of chronic exposure, especially from 5G, remain to be fully understood.

4.2. Emerging Concerns About Non-Thermal Biological Effects

Most regulatory standards, including those set by ICNIRP and Federal Communications Commission (FCC), are based on preventing thermal effects, which occur when RF radiation heats biological tissues. However, a growing body of research suggests that non-thermal biological effects—those occurring without a measurable increase in tissue temperature—could potentially occur at lower radiation levels (Panagopoulos et al., 2013).

- **Non-Thermal Mechanisms**: Proposed mechanisms for non-thermal effects include oxidative stress, DNA damage, and alterations in cell membrane permeability (Margaritis et al., 2014). For example, some animal studies have demonstrated that exposure to RF radiation can lead to increased reactive oxygen species (ROS), which can cause cellular damage (Yakymenko et al., 2016). However, these findings have not been consistently replicated in human studies, and the clinical relevance of non-thermal effects in humans remains highly debated (Zothansiama et al., 2017).
- **Precautionary Principle**: Although the evidence for non-thermal effects is controversial and not universally accepted, it is recommended that they not be dismissed outright, particularly in the context of long-term exposure and vulnerable populations such as children and pregnant women (Frank, 2021). Given that children may be more susceptible to the potential biological effects of RF radiation due to their developing bodies and longer lifetime exposure, more research focusing on this population is needed (Khurana et al., 2010).

4.3. Implications of 5G and Long-Term Exposure

The introduction of 5G networks, which use higher frequency bands such as millimeter waves (30–300 GHz), adds a new layer of complexity to the discussion. While millimeter waves penetrate the body less deeply than lower-frequency RF radiation, they are absorbed primarily in the skin and the eyes, raising concerns about localized exposure effects (Russell, 2018).

- **Long-Term Exposure**: The long-term health effects of chronic exposure to low-intensity RF radiation from both 4G and 5G technologies are not yet fully understood. With 5G technology resulting in the placement of

more base stations in close proximity to populated areas, the cumulative impact of constant exposure at low levels is a key area of ongoing investigation (Cucurachi et al., 2013). The current body of research does not suggest any significant risks from long-term exposure at levels within regulatory limits, but as technology evolves, reassessing safety guidelines may be necessary.

4.4. Conclusion and Need for Ongoing Research

While most of the available research indicates that RF radiation from cell towers does not pose a significant risk to public health at current exposure levels, it is important to continue monitoring the potential long-term effects of this radiation, particularly with the widespread adoption of 5G technology. Given the gaps in knowledge regarding non-thermal effects and the possibility of health risks from chronic, cumulative exposure, it is critical that future studies focus on vulnerable populations and assess the biological mechanisms that may underlie potential health impacts (Miller et al., 2019).

5. Conclusions

The health effects of radiofrequency (RF) radiation from cellular towers remain a topic of scientific and public interest, particularly as the deployment of 5G networks increases. The majority of studies and regulatory bodies, including the WHO and ICNIRP, maintain that current exposure levels from mobile towers are within safe limits and primarily focus on preventing thermal effects. These guidelines are designed to protect against tissue heating and are generally considered effective.

However, concerns persist about potential non-thermal biological effects, such as oxidative stress, DNA damage, and impacts on neurological and reproductive health. While some studies have reported these effects, particularly in laboratory settings, the evidence is inconsistent, and these findings have not been conclusively replicated in human studies. Additionally, the debate over electromagnetic hypersensitivity (EHS) remains unresolved, with research suggesting that psychological factors may play a role in the condition.

In terms of cancer risk, epidemiological studies have produced mixed results. While some suggest a possible increase in certain cancers, such as brain tumors, among those living near cell towers, these studies often face methodological challenges. The International Agency for Research on Cancer (IARC) has classified RF radiation as "possibly carcinogenic to humans" (Group 2B), though this classification reflects limited evidence and not a definitive risk.

Overall, while current scientific consensus suggests that RF radiation from cell towers at regulated levels does not pose a significant risk to public health, uncertainties about long-term exposure and non-thermal effects remain. Continued research, particularly on vulnerable populations and the impact of 5G technology, is needed to better understand these potential risks.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Agarwal, A., Desai, N. R., Makker, K., Varghese, A., Mouradi, R., Sabanegh, E., & Sharma, R. (2009). Effects of radiofrequency electromagnetic waves (RF-EMW) from cellular phones on human ejaculated semen: an in vitro pilot study. Fertility and sterility, 92(4), 1318-1325. https://doi.org/10.1016/j.fertnstert.2008.08.022

[2] Baan, R., Grosse, Y., Lauby-Secretan, B., El Ghissassi, F., Bouvard, V., Benbrahim-Tallaa, L., ... & Straif, K. (2011). Carcinogenicity of radiofrequency electromagnetic fields. The lancet oncology, 12(7), 624-626. https://doi.org/10.1016/S1470-2045(11)70147-4

[3] Belyaev, I., & Markov, M. S. (2015). Biophysical mechanisms for nonthermal microwave effects. https://ec.europa.eu/health/scientific_committees/scheer/docs/emf2022/2015_Belyaev.pdf

[4] Desai, N. R., Kesari, K. K., & Agarwal, A. (2009). Pathophysiology of cell phone radiation: oxidative stress and carcinogenesis with focus on male reproductive system. Reproductive Biology and Endocrinology, 7, 1-9. https://doi.org/10.1186/1477-7827-7-114

[5] Dieudonné, M. (2020). Electromagnetic hypersensitivity: a critical review of explanatory hypotheses. Environmental Health, 19, 1-12. https://doi.org/10.1186/s12940-020-00602-0

[6] Eger, H., Hagen, K. U., Lucas, B., Vogel, P., & Voit, H. (2006). The influence of being physically near to a cell phone transmission mast on the incidence of cancer. Occupational and Environmental Medicine, 63(5). https://www.kiirgusinfo.ee/wp-content/uploads/2018/07/eger_naila_2004.pdf

[7] Elwood, J. M. (1999). A critical review of epidemiologic studies of radiofrequency exposure and human cancers. Environmental Health Perspectives, 107(suppl 1), 155-168. https://doi.org/10.1289/ehp.99107s1155

[8] Fields, R. E. (1997). Evaluating compliance with FCC guidelines for human exposure to radiofrequency electromagnetic fields. Oet Bull, 65(10), 1-57. https://hanklambert.com/attachments/FCCrfExposure.pdf

[9] Foster, K. R., & Moulder, J. E. (2013). Wi-Fi and health: review of current status of research. Health physics, 105(6), 561-575. https://doi.org/10.1097/HP.0b013e31829b49bb

[10] Frank, J. W. (2021). Electromagnetic fields, 5G and health: what about the precautionary principle?. J Epidemiol Community Health, 75(6), 562-566. https://doi.org/10.1136/jech-2019-213595

[11] Hardell, L., & Carlberg, M. (2015). Mobile phone and cordless phone use and the risk for glioma–Analysis of pooled case-control studies in Sweden, 1997–2003 and 2007–2009. Pathophysiology, 22(1), 1-13. https://doi.org/10.1016/j.pathophys.2014.10.001

[12] Hutter, H. P., Moshammer, H., Wallner, P., & Kundi, M. (2006). Subjective symptoms, sleeping problems, and cognitive performance in subjects living near mobile phone base stations. Occupational and environmental medicine, 63(5), 307-313. https://doi.org/10.1136/oem.2005.020784

[13] International Commission on Non-Ionizing Radiation Protection. (2020). Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). Health physics, 118(5), 483-524. https://doi.org/10.1097/HP.0000000000001210

[14] Kesari, K. K., Kumar, S., & Behari, J. (2011). Effects of radiofrequency electromagnetic wave exposure from cellular phones on the reproductive pattern in male Wistar rats. Applied biochemistry and biotechnology, 164, 546-559. https://doi.org/10.1007/s12010-010-9156-0

[15] Kesari, K. K., Kumar, S., & Behari, J. (2011). Effects of radiofrequency electromagnetic wave exposure from cellular phones on the reproductive pattern in male Wistar rats. Applied biochemistry and biotechnology, 164, 546-559. https://doi.org/10.1007/s12010-010-9156-0

[16] Khurana, V. G., Hardell, L., Everaert, J., Bortkiewicz, A., Carlberg, M., & Ahonen, M. (2010). Epidemiological evidence for a health risk from mobile phone base stations. International journal of occupational and environmental health, 16(3), 263-267. https://doi.org/10.1179/107735210799160192

[17] Leszczynski, D. (2014). Radiation proteomics: a brief overview. Proteomics, 14(4-5), 481-488. https://doi.org/10.1002/pmic.201300390

[18] Levitt, B. B., & Lai, H. (2010). Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays. Environmental Reviews, 18(NA), 369-395. https://doi.org/10.1139/A10-018

[19] Loughran, S. P., Verrender, A., Dalecki, A., Burdon, C. A., Tagami, K., Park, J., ... & Croft, R. J. (2019). Radiofrequency electromagnetic field exposure and the resting EEG: Exploring the thermal mechanism hypothesis. International journal of environmental research and public health, 16(9), 1505. https://doi.org/10.3390/ijerph16091505

[20] Margaritis, L. H., Manta, A. K., Kokkaliaris, K. D., Schiza, D., Alimisis, K., Barkas, G., ... & Ziomas, K. (2014). Drosophila oogenesis as a bio-marker responding to EMF sources. Electromagnetic Biology and Medicine, 33(3), 165-189. https://doi.org/10.3109/15368378.2013.800102

[21] Miller, A. B., Sears, M. E., Morgan, L. L., Davis, D. L., Hardell, L., Oremus, M., & Soskolne, C. L. (2019). Risks to health and well-being from radio-frequency radiation emitted by cell phones and other wireless devices. Frontiers in public health, 7, 223. https://doi.org/10.3389/fpubh.2019.00223

[22] Mišík, M., Kundi, M., Worel, N., Ferk, F., Hutter, H. P., Grusch, M., ... & Knasmueller, S. (2023). Impact of mobile phone-specific electromagnetic fields on DNA damage caused by occupationally relevant exposures: results of ex vivo experiments with peripheral blood mononuclear cells from different demographic groups. Mutagenesis, 38(4), 227-237. https://doi.org/10.1093/mutage/gead022

[23] Mohler, E., Frei, P., Braun-Fahrländer, C., Fröhlich, J., Neubauer, G., Röösli, M., & Qualifex Team. (2010). Effects of everyday radiofrequency electromagnetic-field exposure on sleep quality: a cross-sectional study. Radiation Research, 174(3), 347-356. https://doi.org/10.1667/RR2153.1

[24] Pall, M. L. (2018). Wi-Fi is an important threat to human health. Environmental research, 164, 405-416. https://doi.org/10.1016/j.envres.2018.01.035

[25] Panagopoulos, D. J. (2019). Comparing DNA damage induced by mobile telephony and other types of man-made electromagnetic fields. Mutation Research/Reviews in Mutation Research, 781, 53-62. https://doi.org/10.1016/j.mrrev.2019.03.003

[26] Panagopoulos, D. J., Johansson, O., & Carlo, G. L. (2013). Evaluation of specific absorption rate as a dosimetric quantity for electromagnetic fields bioeffects. PloS one, 8(6), e62663. https://doi.org/10.1371/journal.pone.0062663

[27] Repacholi, M. H. (2001). Health risks from the use of mobile phones. Toxicology letters, 120(1-3), 323-331. https://doi.org/10.1016/S0378-4274(01)00285-5

[28] Rubin, G. J., Munshi, J. D., & Wessely, S. (2005). Electromagnetic hypersensitivity: a systematic review of provocation studies. Psychosomatic medicine, 67(2), 224-232. https://doi.org/10.1097/01.psy.0000155664.13300.64

[29] Russell, C. L. (2018). 5 G wireless telecommunications expansion: Public health and environmental implications. Environmental research, 165, 484-495. https://doi.org/10.1016/j.envres.2018.01.016

[30] Russell, C. L. (2018). 5 G wireless telecommunications expansion: Public health and environmental implications. Environmental research, 165, 484-495. https://doi.org/10.1016/j.envres.2018.01.016

[31] Schoeni, A., Roser, K., & Röösli, M. (2015). Symptoms and cognitive functions in adolescents in relation to mobile phone use during night. PloS one, 10(7), e0133528. https://doi.org/10.1371/journal.pone.0133528

[32] Simkó, M., & Mattsson, M. O. (2019). 5G wireless communication and health effects—A pragmatic review based on available studies regarding 6 to 100 GHz. International journal of environmental research and public health, 16(18), 3406. https://doi.org/10.3390/ijerph16183406

[33] Smythe, J. W., & Costall, B. (2003). Mobile phone use facilitates memory in male, but not female, subjects. Neuroreport, 14(2), 243-246. https://doi.org/10.1097/00001756-200302100-00017

[34] Vecchia, P. (Ed.). (2011). Exposure to High Frequency Electromagnetic Fields, Biological Effects and Health Consequences (100 KHz-300 GHz): Review of the Scientific Evidence on Dosimetry, Biological Effects, Epidemiological Obeservations, and Health Consequences Concerning Exposure to High Frequency Electromagnetic Fields (100 KHz-300 GHz). ICNIRP. https://www.emf.ethz.ch/fileadmin/redaktion/public/downloads/4_wissen/externes_material/ICNIRP_effekte_RFReview.pdf

[35] World Health Organization. (2011). Electromagnetic fields and public health: mobile phones (Fact sheet number 193).

[36] Yakymenko, I., & Sidorik, E. (2010). Risks of carcinogenesis from electromagnetic radiation of mobile telephony devices. https://dspace.nuft.edu.ua/handle/123456789/15576

[37] Yakymenko, I., Tsybulin, O., Sidorik, E., Henshel, D., Kyrylenko, O., & Kyrylenko, S. (2016). Oxidative mechanisms of biological activity of low-intensity radiofrequency radiation. Electromagnetic biology and medicine, 35(2), 186-202. https://doi.org/10.3109/15368378.2015.1043557

[38] Zothansiama, Zosangzuali, M., Lalramdinpuii, M., & Jagetia, G. C. (2017). Impact of radiofrequency radiation on DNA damage and antioxidants in peripheral blood lymphocytes of humans residing in the vicinity of mobile phone base stations. Electromagnetic biology and medicine, 36(3), 295-305. https://doi.org/10.1080/15368378.2017.1350584