Original Article

Exposure to electromagnetic waves for reducing brain health: A bibliometric analysis

Ida Ayu Gede Winda Savitri[1], I Made Dwi Mertha Adnyana[1,2,3,4], I Wayan Wahyudi[1]*, Gusti Ayu Putu Wahyu Purnama Dewi[1], Indria Ariastuti[1], Ni Luh Putu Ari Sundari[1], Pande Komang Aditya Ryan Nuartha[1]

[1] Department of Biology, Faculty of Information Technology and Science, Universitas Hindu Indonesia, Sangalangit Street, Tembau, Penatih, East Denpasar, 80238, Indonesia; [2] Associate Epidemiologist, Indonesian Society of Epidemiologists, Jalan (Street) Percetakan Negara No. 29 23, RT.23/RW.7, Johar Baru, Daerah Khusus Ibukota Jakarta 10560, Indonesia; [3] Department of Tropical Medicine, Faculty of Medicine, Universitas Airlangga, Jalan Prof. Dr, Moestopo, 47, Pacar Kembang, Surabaya, 60132, Indonesia; [4] One Health Laboratory Network (OHLN), Indonesia

ABSTRACT

Background: Exposure to electromagnetic waves has been reported to have an adverse impact on human brain health. Various claims have revealed the impact of long-term exposure to electromagnetic waves clinically and nonclinically, but there are no comprehensive studies that explain the effects of electromagnetic wave exposure on human brain health. **Objective:** This study aimed to identify the effects of electromagnetic wave exposure on human brain health. **Methods**: Using a meta-synthesis approach and bibliometric analysis. A total of 271 articles from Scopus, Web of Science and PubMed were screened to obtain 148 terms and analyzed descriptively. **Results**: The findings from 2004–2024 articles that met the selection criteria resulted in 10 major clusters, 903 networks and 4,020 network strengths. The terms "1800 MHz mobile phone", "900 MHz", "acute exposure", "assessment", "behavior", "bioeffect", "biological effect", "biological tissue", "blood brain barrier", "cell phone radiation", "cellular phone", "cellular telephone", "central nervous system", "child", "chronic exposure" and others were most studied. Increased use of electronic devices and wireless technology significantly affects information processing and storage; disrupts synaptic communication and neuronal signaling; causes cognitive decline; disrupts the integrity of the blood-brain barrier; and causes hypersensitivity through disruption of monoamine neurotransmitter metabolism, decreased dopamine levels, norepinephrine and epinephrine levels, 5-hydroxytryptamine "serotonin", excitatory amino acid neurotransmitters and acetylcholine esterase (AChE). **Conclusion**: The increased use of electronic devices and wireless technology significantly affects brain performance and health. Thus, it is important to minimize the effects of exposure to electromagnetic waves.

KEYWORDS
Electromagnetic waves, brain health, radiobiology, toxicology, public health

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CORRESPONDENCE
I Wayan Wahyudi
Department of Biology, Faculty of Information Technology and Science, Universitas Hindu Indonesia;
wahyudi@unhi.ac.id

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INTRODUCTION

A The advent of advanced technology has resulted in a range of alarming impacts on public health, including psychological disorders, organ damage and the impact of radiation generated from electromagnetic waves [1]. The irresponsible use of technology will raise the perspective of problems for health, the environment, and other sectors. Recently, the use of gadgets has generated controversy in the medical world, especially the resulting effects on changes in brain memory in storing information, including decreased brain cell performance, which has implications for long-term damage and disorders. In addition, device radiation, infrared light, and headset Bluetooth have been reported to have negative impacts, including reduced sleep quality, hearing loss and impaired brain stimulus function [2,3].

With the widespread use of electronic devices and wireless technology in society, electromagnetic waves have become an integral part of modern life. Electromagnetic waves are generated from the interaction between magnetic and electric fields that cause vibrations in mutually perpendicular directions. Magnetic fields and electric fields can form electromagnetic waves, namely, transverse waves, where the direction of propagation is perpendicular to the direction of vibration [4,5]. The rising direction and vibrating direction become repetitive cycles that are capable of providing changes, especially to the human brain. The increasing use of electronic devices and wireless technology has raised concerns about the potential effects of electromagnetic waves on brain health [6,7]. Previous studies have investigated the effects of electromagnetic waves on brain health with mixed results and inconsistent findings. A number of studies have suggested that exposure to electromagnetic waves sourced from gadgets, televisions, radios, smart devices, WiFi, base stations and other devices increases stimulation and thermal and nonthermal effects on the human body [3,8,9].

Despite growing concerns about the effects of electromagnetic waves on brain health, there is still a lack of comprehensive and systematic reviews on this topic. This review aims to provide a comprehensive and systematic overview of the effects of exposure to electromagnetic waves on brain health. It is hoped that this review will provide information to the public regarding the dangers and issues associated with minimizing the impact of electromagnetic waves on brain health and other organs.

MATERIALS AND METHODS

This review was systematically organized using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines [10]. This research sought to identify the effects of exposure to electromagnetic waves on human brain health using a literature review. This study used keywords for a literature search using *Boolean* operators (AND' OR), including "effect" AND "Electromagnetic Waves" OR "EMF", "human brain", "Brain", "Memory", "Brain Nerve Disorder" OR "health risk" AND "Human Brain", in three databases, Scopus, Web of Science and PubMed. The selected articles had to meet the inclusion criteria, including articles published in the range of 2004-2024, discussing the impact of electromagnetic wave exposure on brain health, coming from Scopus-indexed reputable journals (Quartile 1-4), Web of Science with *core collection*, English language and original articles and/or short communications and/or research articles and open access. All the data were analyzed descriptively, and the research gaps, research originality and research trends were mapped via bibliometric analysis with the VOSviewer version 1.6.20 application [11].

RESULTS

Publication metrics

Based on the search results using publish or perish (PoP) software, 271 articles were obtained that discussed the effects of electromagnetic wave exposure on human brain health; these included 189 Scopus and Web of Science indexed articles and 82 PubMed indexed articles. Article screening was conducted following PRISMA guidelines. The literature search used the Publish or Perish 8.9.4538.8589 tool with MacOS (arm64) edition, running on Darwin 23.1.0 (arm64*)*. The

results of the citation metric analysis revealed publication years ranging from 2004–2024, with 19 citations per year (2004–2023). The publication metrics in this study are as follows: citation years: 19 (papers: 200; citations: 60,331; citations/year: 3175.32 (acc1=199, acc2=198, acc5=192, acc10=155, acc20=89); citations/paper: 301.66; citations/author: 24896.29; papers/author: 81.30; authors/paper: 3.42/3.0/4 (mean/median/mode); age-weighted citation rate: 8143.17 (sqrt=90.24), 3058.53/author; Hirsch h-index: 127 (a=3.74, m=6.68, 53754 cites=89.1% coverage); egghe g-index: 200 (g/h=1.57, 60331 cites=100.0% coverage); pop hi, norm: 79; pop hi, annual: 4.16; and fassin ha-index: 42.

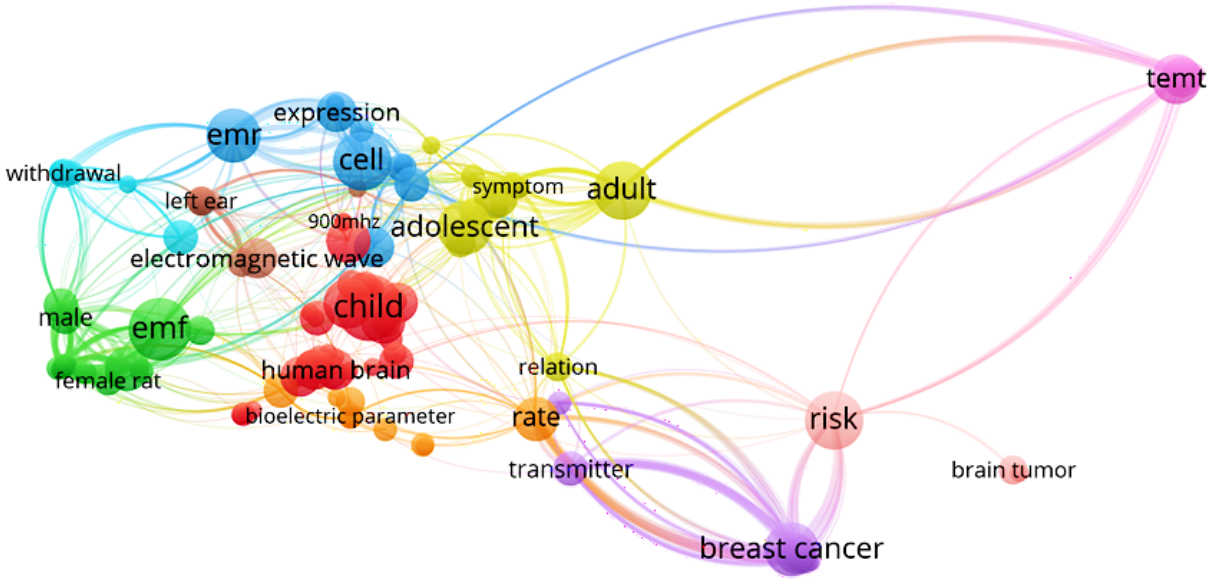

Figure 1. Network visualization by cluster (n=10)

Network Visualization

Network mapping analysis of 271 selected articles revealed 1,078 terms related to the effects of electromagnetic wave exposure on human brain health, but only 148 terms were suitable and consisted of 10 clusters (Figure 1). Each consists of 45 items (cluster 1), 18 items (cluster 2), 16 items (clusters 3 and 4), 12 items (cluster 5), 10 items (cluster 6), 10 items (cluster 7), 9 items (cluster 8), 8 items (cluster 9) and 4 items (cluster 10). In this study, cluster 1 (red nodes and lines) is the most common keyword related to electromagnetic wave exposure in human brain health disorders and is characterized by "1800 MHz mobile phone", "900 MHz", "acute exposure", "assessment", "behavior", "bioeffect", "biological effect", "biological tissue", "blood brain barrier", "cell phone radiation", "cellular phone", "cellular telephone", "central nervous system", "child", "chronic exposure", "computation", "gsm", "head tissue", "health risk", "heating", "human brain", "human head", "mhz electromagnetic radiation", "microwave", "permeability", "possible health effect", "radio", "radio", "wireless communication", "rf exposure", "sar", "wireless communication", and "temperature increase".

The findings showed that out of 148 terms, 903 networks were generated, and the network strength was 4,020. Thicker nodes and lines indicate a stronger network. A shorter distance between nodes indicates that the strength of the term is significantly correlated. Based on these findings, the effects of exposure to electromagnetic waves that have been reported to be harmful to human health, especially the brain, are at 900–1800 MHz, with the greatest effects caused by biological changes in body cells and tissues, changes in brain cells and their performance. Continuous exposure to electromagnetic waves has an impact on reducing tissue and cell permeability and blocking blood flow into the brain accompanied by the risk of brain cancer, narrowing of blood vessels and premature cell death.

Overlay Visualization

Based on the results of keyword distribution analysis and mapping, the effects of electromagnetic wave exposure on brain health were reported from 2005 to 2020. However, there has been a change in research trends over the last two decades. From 2005 to 2010, research focused on the impact of electromagnetic wave exposure on breast cancer incidence, health risk analysis and brain tumor incidence, while from 2011 to 2015, it evolved and focused on children and adolescents; from 2016 to the present, it focused on gene, cell and tissue expression, high and low electromagnetic wave radiation (EMR, electromagnetic radiation), and the effects of electromagnetic waves on the human brain (Figure 2).

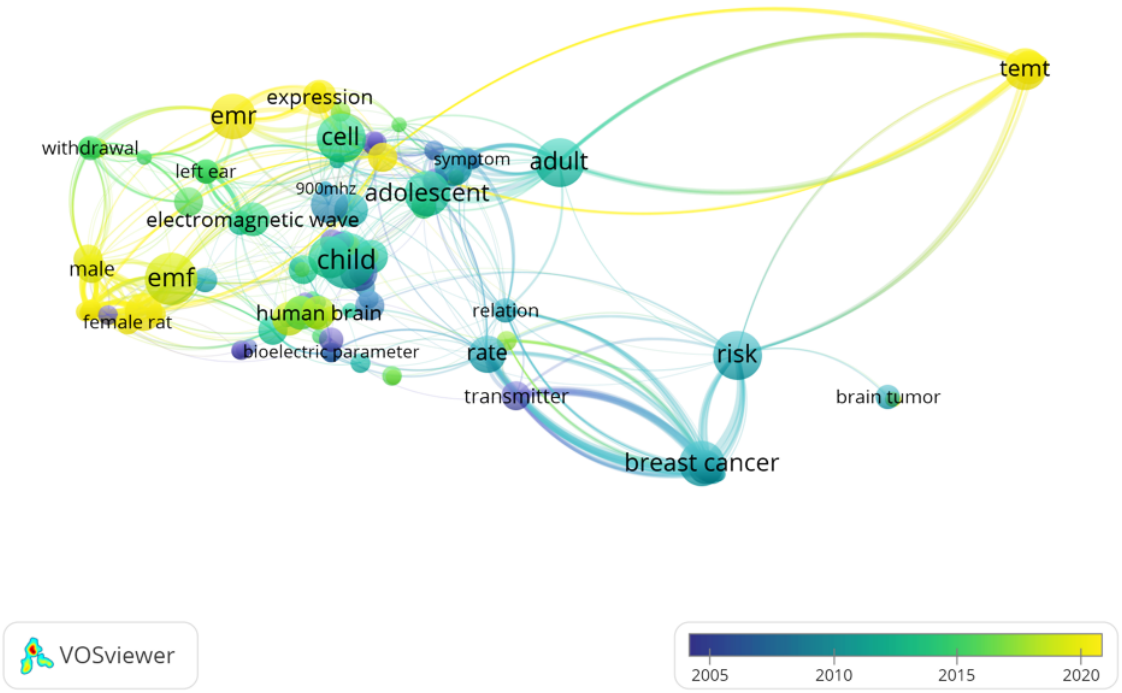

Figure 2. Overlay visualization by term (n = 148)

Density Visualization

Based on the acuity and depth of previous research, there is considerable research space related to the effects of electromagnetic wave exposure on nerves that act as *neurotransmitters* in the brain, including the risk of cell and tissue disruption, information storage ability and the risk of future brain tumors or other brain health disorders. Figure 3 shows the colors - bright yellow indicates the keywords that appear most frequently in 271 research articles and for which the terms have been researched in depth.

DISCUSSIONS

Epidemiologic studies and clinical evidence

Epidemiologic studies related to the effects of exposure to electromagnetic waves have raised awareness as well as concerns of all elements of society about the dangers posed by these waves in the long term [12]. The complexity of the mechanisms involved has led to many studies that have produced new findings and have contributed to the treatment of electromagnetic wave exposure. The use of gadgets, WiFi, microwaves, radios, televisions and laptops are sources ofelectromagnetic waves that certainly have a negative effect on the human body, especially the brain [3,13,14]. Exposure to electromagnetic waves in a certain period of time can cause health problems such as headaches, sleep disturbances, and decreased brain impulses in transmitting messages to brain cancer patients [15].

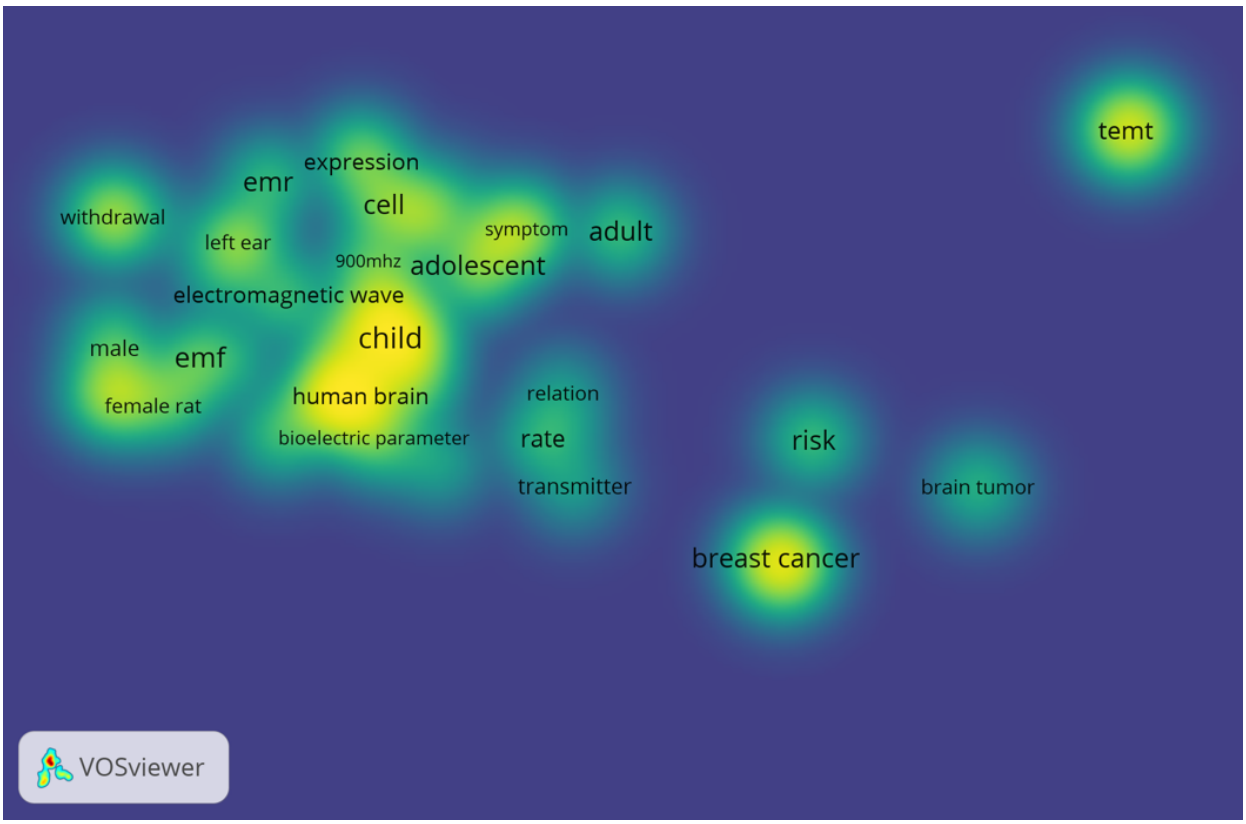

Figure 3. Density visualization by term depth (n=148)

Numerous studies have revealed that radiation generated from electromagnetic waves can cause biological damage to humans through heating because the human body is composed of approximately 65-70% water, electrolytes, and ions. Radiofrequency radiation emitted by cell phones interacts with the human body and interferes with the body's natural healing, resulting in the displacement of electrolytes and ions in the body. Mat et al. [16] reported that GSM 900 MHz cell phones produced the greatest increase in body electrolyte and ion temperatures compared with GSM 1800 MHz cell phones. This indicates that 900 MHz GSM has a greater thermal radiation or heating effect and accelerates brain and tissue cell damage. In his research, he explained that using a headset and earphone Bluetooth device when talking through the device can produce less radiation because the direct radiation signaling from the cell phone antenna is reduced.

In addition, research by Aboul Ezz et al. [17] revealed that daily exposure to electromagnetic waves for 1 h with an electromagnetic wave frequency of 1,800 MHz, a specific absorption rate (SAR) of 0.843 W/kg, and a power density of 0.02 mW/cm^2 induced a significant decrease in dopamine (DA) in the hippocampus after 2 months of exposure and 1 month after cessation of exposure. This study suggested that exposure to electromagnetic waves can reduce dopamine production in the hippocampus, which can affect the arousal of mice and contribute to a decrease in learning and memory ability after exposure to electromagnetic waves. Research by Jing et al. [9] also revealed that exposure to electromagnetic waves can cause metabolic disorders of monoamine neurotransmitters in the brain, depending on the intensity of exposure to wave radiation at a frequency of 900 MHz and an SAR value of 0.9 W/kg. This study showed that exposure to electromagnetic waves causes abnormal dopamine content in the central nervous system of rat fetuses and leads to the slow development of the rat brain.

Furthermore, a number of studies have revealed that exposure to electromagnetic waves significantly reduces the levels of norepinephrine and epinephrine, 5-hydroxytryptamine (serotonin), excitatory amino acid neurotransmitters, excitatory amino acid neurotransmitters, and acetylcholine esterase (AChE) [18–23]. These levels are important for the information signaling system of the brain. Exposure to electromagnetic waves for a very long period of time

risks increasing changes in nerve cells of the central nervous system, including nerve cell apoptosis, changes in nerve myelin function and ion channels and induction with high doses acting as a source of stress on the brain and other disorders that have a high risk of triggering death in the brainstem [21,24–26].

Mechanisms and effects of electromagnetic wave exposure on the brain

Although the mechanisms and effects of electromagnetic wave exposure on the brain have long been studied, further scientific investigations are needed to provide a comprehensive understanding of these mechanisms and their implications for human health. A brief overview of the mechanism by which electromagnetic wave exposure affects brain health is presented in Figure 4. In this study, we found that constant exposure to electromagnetic waves can promote calcium ion balance disturbance, the induction of oxidative stress, the modulation of neurotransmitter levels, changes in brain wave patterns, and structural changes in the brain [27,28]. Exposure to electromagnetic waves can affect delicate neural structures in the brain. Postexposure to brain tissue results in changes in the electrical activity of neurons by altering the flow of ions across the neuronal membrane [21]. This disruption of ion flow can affect the pattern of activation and communication between neurons, potentially affecting the processing and storage of information in the brain [29].

Furthermore, electromagnetic wave fields are capable of oscillating at certain frequencies, resulting in changes in biological tissues and conducting currents, potentially disrupting normal cellular processes. This can trigger changes in the concentration of calcium ions within the brain, as these ions fulfill cellular functions such as neurotransmitter release and cell signaling [3,4,23]. If calcium ions enter brain cells, they disrupt the balance and disturb the signaling process in the cells. Neurotransmitters are chemical messengers that enable communication between neurons. Therefore, the signaling system in the brain is important for body cells. Disruption of this neurotransmitter balance can disrupt synaptic communication and contribute to decreased signaling and information processing within the brain [12,16].

Prolonged or intense exposure to electromagnetic fields has been linked to changes in neural functions and structures. Changes in synaptic plasticity trigger a decrease in the ability of synapses within the brain, which leads to a decrease in cognitive functions, such as learning, sensing, and memory [1,3,19]. Another risk is that a decrease in the balance of signaling molecules could contribute to changes in brain function and behavior. Furthermore, electromagnetic fields can induce the production of reactive oxygen species (ROS) in human brain cells. ROS are chemically reactive molecules that can damage cellular structures, including proteins, lipids, and DNA, as a result of the accumulation of free radicals that trigger calcium release. Changes in gene and enzyme levels result in the activation of downstream signaling pathways, especially the mitochondria-dependent caspase-3 pathway, and can cause neuronal apoptosis, behavioral manifestations, and pathophysiological changes in the brain [25]. Increased ROS production under electromagnetic wave exposure can lead to a high accumulation of oxidative stress, which is implicated in neurological disorders and cognitive decline in the brain.

Finally, massive exposure to electromagnetic waves can disrupt the permeability of the blood–brain barrier (BBB). The permeability of the BBB serves as a protective barrier that regulates the passage of substances from the bloodstream to the brain [30]. A high accumulation of electromagnetic fields in the blood can disrupt the integrity of the BBB, which has an impact on the support of blood flow to the brain, causing harmful substances to enter the brain more easily and worsening neurological conditions. It is characterized by hypersensitivity (electrical sensitivity). Hypersensitivity is a marker of physiological disorders caused by electromagnetic wave radiation and is characterized by headaches, excessive fatigue, and sleep disturbances (insomnia) accompanied by tachycardia, vomiting, muscle pain, ringing in the ears, muscle spasms, psychiatric disorders, and impaired concentration. If this condition continues to worsen, it will have a direct impact on the body's daily productivity until the death of cells, tissues, and organs [12,15,26]. Thus, the adverse effects resulting from the use of products that generate electromagnetic fields make it important to maximize their limited and necessary use.

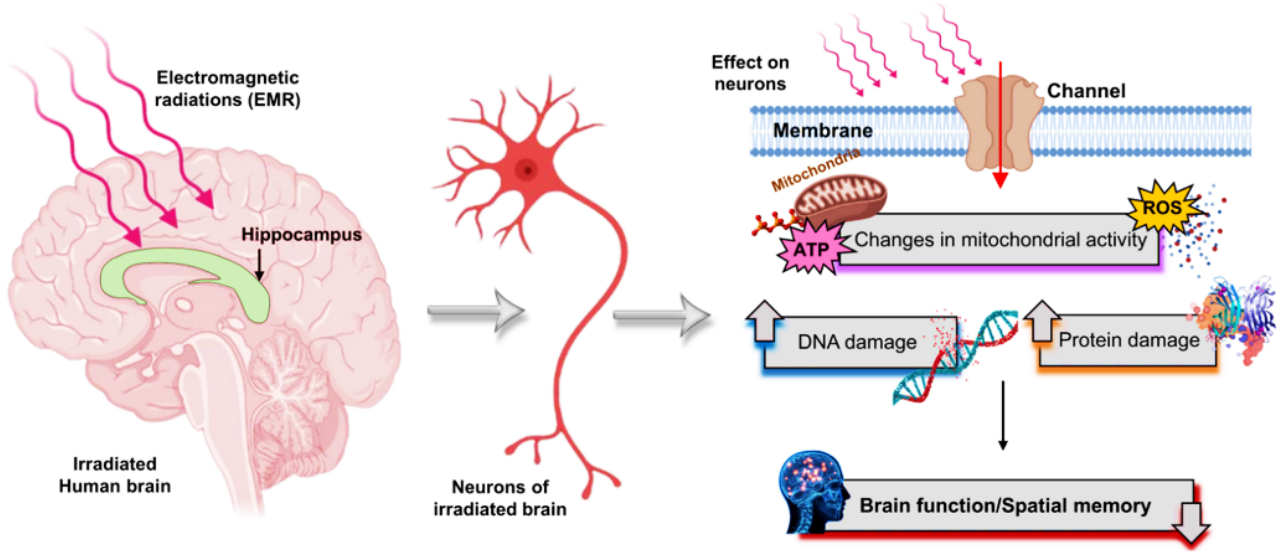

Figure 4. Brief mechanism of electromagnetic wave exposure in brain health

Lessons learned

The lessons learned from the effects of exposure to electromagnetic waves and their impact on human brain health highlight several important points, including the importance of a more comprehensive exploration of the evidence. Current research on exposure to electromagnetic waves and their effects on the human brain provides mixed and inconclusive results, although some studies have shown a potential relationship between long-term exposure to certain frequencies and adverse health effects. However, other studies have not found a significant correlation, so it is important to improve the quality of the research, especially that related to bioelectric parameters. In addition, the precautionary principle is applied by limiting exposure to high-intensity electromagnetic fields and using shielding or an appropriate distance from the exposure source. It is important to provide protection and information to at-risk populations such as toddlers, children, and pregnant women to reduce the incidence of cancer, disability, and psychological and mental disorders and to study the short- and long-term effects on various subjects and intensities to comprehensively determine the effects of exposure to electromagnetic fields on brain health.

Future research

Future research on electromagnetic wave exposure and its impact on human brain health should focus on improving research methodologies, understanding the underlying mechanisms, assessing emerging technologies, and fostering collaboration. This study will contribute to more informed guidelines and policies regarding the effects of electromagnetic wave exposure on human health. First, improving the quality of research methodologies, including large-scale and long-term studies, standardized measurement techniques, and control groups, is important for establishing rigorous research designs. This will help establish more reliable conclusions regarding the impact of electromagnetic wave exposure on human brain health. Second, there is a need for an improved mechanistic understanding, and investigating the underlying mechanisms by which electromagnetic waves can affect the brain is crucial by studying the interaction of wave exposure with brain tissue at the cellular and molecular levels, elucidating potential biological pathways, and facilitating the development of targeted interventions. Third, the massive development of technology is driving the importance of evaluating the impact of 5G networks, wearable devices, and other new sources of exposure to electromagnetic waves. Fourth, increased collaborative efforts between researchers, the government, and industry stakeholders are essential to ensure a comprehensive understanding of the impacts of electromagnetic wave exposure. This collaboration can help establish standardized guidelines, improve data sharing, and facilitate robust risk assessment in the future.

CONCLUSIONS

The increased use of electronic devices and wireless technology significantly affects information processing and storage, disrupts synaptic communication and neuronal signaling and cognitive decline, disrupts the integrity of the blood–brain barrier, and produces hypersensitivity in the brain through disruption of monoamine neurotransmitter metabolism, decreased dopamine levels, norepinephrine and epinephrine levels, 5-hydroxytryptamine "serotonin," excitatory amino acid neurotransmitters, and acetylcholine esterase (AChE). Thus, it is important to comprehensively minimize the effects of exposure to electromagnetic waves in society. Further research is needed regarding the dose of electromagnetic wave exposure that alters the makeup and performance of the central nervous system and the underlying mechanisms involved.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization: IMDM, IAGWS; Methodology: IMDM, IA; Software: IMDM, IAGWS; Validation: IMDM, IWW, PKARN; Formal analysis: IMDM, GAPWPD; Investigation: IAGWS, IWW, NLPAS; Resources: GAPWPD, IA, PKARN; Data Curation: IMDM, IA; Writing - Original Draft: IMDM, IA, NLPAS; Writing - Review & Editing: IMDM, PKARN; Visualization: IAGWS, GAPWPD; Supervision: IMDM, IWW.

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