

et al. demonstrated the effect of EMR (1.8 GHz) on human spermatozoa and reported that the EMR exposure enhances mitochondrial reactive oxygen substances (ROS) generation by human spermatozoa, decreasing the vitality, and motility of spermatozoa cells.^[36]

Neurotoxic effects

EMR exposure alters the neuronal activities of the brain and affects learning and memory process of the brain. Shahin *et al.* studied the effect of short- (15 days) and long-term (30 and 60 days) exposure of low-level 2.45 GHz microwave radiation-induced local stress in adult male mice and reported that microwave radiation exposure increased serum corticosterone level. The expression of corticotropin-releasing hormone (CRH), CRH-receptor 1, and inducible nitric oxide synthase (i-NOS) had increased, while the expression of ionotropic glutamate receptors, neuronal NOS, postsynaptic density protein 95, protein kinase C ϵ , protein kinase A, and cyclic adenosine monophosphate responsive element binding protein decrease in hippocampal subregions in a duration-dependent manner.^[19] Eser *et al.* also studied the effect of electromagnetic waves in the frontal cortex, brain stem, and cerebellum of rats and found severe degenerative changes, extensively dark pyknotic nuclei, and shrunken cytoplasm in the electromagnetically irradiated group.^[37] The preclinical laboratory studies have shown that, EMR may open the blood–brain barrier, increases the permeability of toxic substances into the brain, and impair spatial memory.^[38] Long-term exposure of EMR radiation from GSM base station also caused impairment in the levels of neurotransmitter such as adrenaline, noradrenaline, and dopamine.^[39]

Effect on behavior

Erogul *et al.* studied the effect of mobile phone tower radiation in male volunteer and found that EMR emitted by cell phone tower does not have any effect on the short-term, and they concluded that the long-term exposure might lead to behavioral alterations or structural changes of male germ cells.^[40] The hippocampus is the part of the brain which is involved in origination and memory forming which is affected by EMR, and it caused structural damage to the brain due to albumin leakage from blood–brain barrier, increased grooming, reduced locomotor activity, and increased basal corticosterone levels.^[41] In children, radiofrequency EMR exposure caused more behavior problem to compare with children with lower exposure.^[42]

Oxidative stress

Oxidative stress is an imbalance between the productions of tissue-damaging free radical and ability of the body

to detoxify the harmful effects through neutralization by antioxidants. A review from the Yakymenko *et al.*, showed 93 out of 100 peer-reviewed studies indicate that radiofrequency EMR increases oxidative stress.^[43] Widespread use of cell phones also increases the anxiety level due to EMR radiation exposure.^[44] Çelik *et al.* reported an excessive production of ROS and reduced antioxidant defense systems (increased levels of lipid peroxidation and decreased levels of glutathione peroxidase, Vitamin A, Vitamin E, and β -carotene) in the pregnant rats (exposed with Wi-Fi radiation).^[45]

Genotoxic effect

Although EMR may not directly damage DNA in human, research indicates that they could cause a series of biological impacts in to the human body that results in genetic damage. A study was carried out by Dasdag *et al.* on Wistar Albino adult male rats to study the long-term effects of radiofrequency radiation emitted from a Wi-Fi system on microRNAs in the brain tissues and concluded that long-term exposure (12 months) of 2.4 GHz radiofrequency radiation may lead to the development of neurodegenerative diseases due to alteration of expression of some microRNAs.^[46]

Cardiovascular system

EMR may affect the cardiovascular system, and probably increase heart rate, arrhythmias, and changes blood pressure. In the cardiovascular system, Wi-Fi radiation affects heart rhythm, blood pressure, catecholamines action, and increases PR and QT intervals.^[47,48]

Sleep

Sleep is very essential to human as good quality of sleep grants us to focus efficiently and perform better in our daily life, but the quality of sleep is affected by the environmental risk factor which includes EMR. EMR can alter the quality of sleep by delaying entrance into deep nonrapid eye movement (NREM) sleep and decreasing time spent in this stage of sleep. Mohammed *et al.* studied the effect of EMR on rodent sleep pattern using 900 MHz unmodulated wave and 900 MHz modulated at 8 and 16 Hz waves and reported an increase in rapid eye movement (REM) latency after irradiation indicating a change in the ultradian rhythm of normal sleep cycles.^[49]

Effect on environment

EMR is not new to the environment. In most of the places, ELF fields generated by communication devices, mobile tower, and overhead power cables which may alter plants and animals growth. Plants are under the influence of the Earth's geomagnetic field, and the external application of an MF

or an HF nonionizing electromagnetic fields (EMFs) may alter the growth and development of plants in *ex vitro* and *in vitro* conditions. Liptai *et al.* reported that EMR from Wi-Fi router might reduce plants growth and can cause genetic mutations.^[50] Halgamuge *et al.* also reported the reduction of epicotyl and hypocotyl growth in soybean seeds after exposure to weak microwave radiation.^[51] HF-EMF radiation is noninjurious, but its long-term impact on metabolic changes in plants remains unclear.^[52] Ozlem-Caliskan *et al.* investigated the effect of EMF on parasite growth and reported that EMF exposure might decrease in the number of parasites, and EMF has some effect on the growth of parasites which needs to be investigated further.^[53]

CONCLUSION

EMRs are wide applications and commonly used for wireless communication devices such as radio, mobile phones, satellite signals, and also used for diagnostic purposes (e.g., X-rays, gamma rays). Health hazards of ionizing EMR are well studied, but the health hazards of nonionizing EMR are under investigations. In general, people believe that nonionizing EMR radiations are not having much health hazards. In preclinical studies, long-term exposure of EMR to plants and animals showed a reduction in growth and inference with the generation of free radicals. In the current century, avoid using nonionizing EMR is not possible, since it has a wider application in the fields of telecommunications and medicine. Wisely use nonionizing EMR may enhance the quality life, instead of discussing the health hazards of nonionizing EMR.

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Conflicts of interest

There are no conflicts of interest.

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