Review Article

Health hazards with electromagnetic radiation

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Abstract

Electromagnetic spectrum (EMS) is the range of frequencies of electromagnetic radiation (EMR). In general, EMR can be classified into ionizing or nonionizing radiation (NIR), based on their energy possessed to knock electrons off atoms that it interacts with. Ionizing radiation holds a great number of energy to knock off electrons and ionize the matter, whereas NIR does not possess enough energy to ionize atoms or molecules. Ionizing radiation can be further divided into five types, namely, alpha-particles, beta-particles, gamma-ray, X-rays, and neutron particles. NIRs are part of EMS encompass the wavelength (>100 nm), low photon energy (<12.4 eV) portion of the EMS from 1 Hz to 3×10^{15} Hz. NIR is divided into four regions, namely, static electric and magnetic field, extremely low-frequency filed, radiofrequency, and microwave radiation and optical radiation. NIR can be from both natural (e.g., sunlight) and man-made sources (e.g., wireless communications devices). EMR exposures can be divided into three categories, which is high-level, medium-level, and low-level exposure. High-level radiation exposure can cause damage to the body, and the affected cells cannot repair fast enough with a dose that may quickly kill the exposed person. EMR is hazardous to all living organisms because its effects are latent, painless, and cumulative. The current review is to summarize the effect of EMR exposures on physical and mental health.

Keywords: Electromagnetic radiation, health hazards, mobile phone, oxidative stress

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INTRODUCTION

In our daily life, we are surrounded by electromagnetic radiation (EMR), there are emitted from the environment, radio, television, medical diagnostic, and communication devices such as cell phones, and also Wi-Fi routers. Radiation from cell phone and Wi-Fi is the radiation that we encountered the most in our life, and this resulted in increased human exposure to electromagnetic radiation and health risks. The current review is to summarize the effect of EMR exposures on physical and mental health.

ELECTROMAGNETIC RADIATION

Electromagnetic radiation (EMR) is a form of energy generated by oscillation of electric and magnetic disturbance, or by the movement of electrically charged particles (e.g. electron) traveling through a vacuum or material medium. The electric and magnetic field (MF) oscillates in planes mutually perpendicular to each other, and thus create the disturbance. EMR propagated through a material medium or through free space in the form of electromagnetic waves. The EMR has certain unique characteristics, given as frequency, energy, or wavelength.[1]

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Electromagnetic spectrum (EMS) is the continuum of all electromagnetic according to the frequency of wavelength of electromagnetic wave. The EMS is commonly divided into seven regions, in order of decreasing wavelength and increasing energy and frequency. The common designations (from low frequency to high frequency [HF]) are radiowaves, microwaves, infrared ray, visible right, ultraviolet (UV), X-rays, and gamma (γ) rays [Figure 1]. The various regions bear different names based on their differences in behavior in the transmission, emission, and absorption of the corresponding waves. Different regions of EMS have their own application in our daily life.[2] EMR can be classified into ionizing or nonionizing radiation (NIR), based on their energy possessed to knock electrons off atoms that it interacts with.

Ionizing radiation

Ionizing radiation holds a great number of energy to knock off electrons and ionize the matter.[3] Ionizing radiation can be further divided into five types, namely, alpha (α)-particles, beta (β)-particles, gamma (γ)-rays, X-rays, and neutron particles [Figure 2]. These types are caused by unstable atoms that have either an excess of mass or energy (or both). To reach a more stable state, they are required to release the extra energy or mass (or both) in the form of radiation.[4]

Nonionizing radiation

NIRs are part of EMS encompass the wavelength (>100 nm), low photon energy (<12.4 eV) portion of the EMS from 1 Hz to 3 × 10^{15} Hz. In EMS, NIR is divided into four regions, namely, static electric and MF (0 Hz), extremely low frequency (ELF) filed (>0 Hz–300 Hz), radiofrequency, and microwave radiation (300 Hz–300 Ghz) and optical radiation. Optical radiation is further classified as infrared (760 – 10^6 nm), visible (400–760 nm), and UV radiation (100–400 nm) [Figure 1]. NIR originates from natural origin (sunlight) and man-made (wireless communications).[5,6]

NIR does not possess enough energy to ionize atoms or molecules by removing it, but it has enough energy to move atoms in a molecule around or cause them to vibrate. Wave with low frequency such as radio- and microwave energy is NIR.[7] It is considered as harmful only to the extent of the amount of heat energy it transfers to matter it hits. NIR can penetrate into the human body. Depend on the energy and exposure time of NIR, it can cause localized heating or photochemical reaction may occur with possible permanent harm to the body.[5] Normally, we are all surrounded by NIR emitted from natural and man-made sources.

CATEGORIES OF ELECTROMAGNETIC RADIATION

EMS is the range of frequencies of EMR. In general, EMR exposures can be divided into three categories, which is high-level, medium-level, and low-level exposure.

- High-level radiation exposure can cause damage to the body and the affected cells cannot repair fast enough with a dose that may quickly kill the exposed person. Example of high-level exposure is radiation from atomic weapons. However, a high level of exposure is beneficial to human in some cases within a controlled situation (e.g. cancer radiotherapy). In cancer therapy, concentrated beams of radiations are directed to the cancerous cell and destroy them at the affected area in the body. These high doses of high-level radiation (doses of >1000 mSv) tend to kill cells and make organs to be damaged immediately. During the 1986 Chernobyl disaster, approximately 134 plant workers and firefighters at the Chernobyl nuclear power plant received high radiation dose ranging between 800 and 16,000 mSV. After the incident, they are suffered from acute radiation sickness, and out of these people, 28 died within the first 3 months from their radiation injuries.[8]
- Medium-level radiation exposure may cause damage to living cells. The cells are permanently damaged

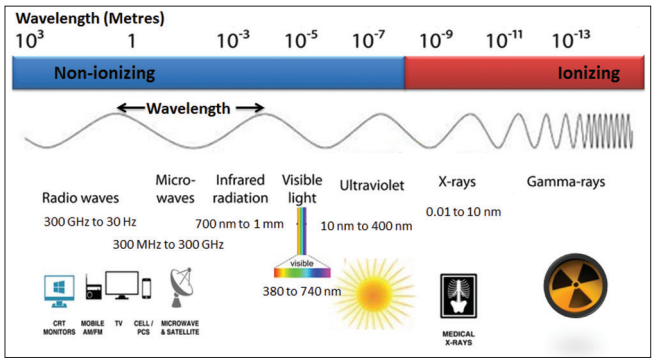

Figure 1: Electromagnetic radiation spectrum

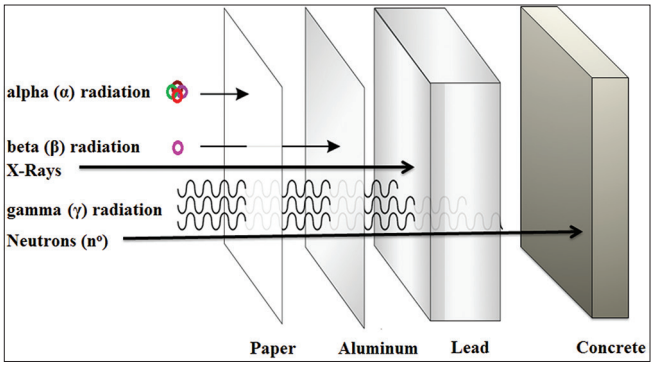

Figure 2: Five different types of ionizing radiation

and changed, thus it may go on to produce cells with abnormality when they undergo cell division. Under such circumstances, they may become tumorous, but they may take many years to appear. Medium-level radiation exposure (<100 mSv) may have the potency to cause hereditary effects in the children who are exposed to radiation. Such effects may increase the rate of natural mutation to an inappropriate degree.[9,10]

- Low-level radiation exposure is a result of radiation at mines or natural background radiation where the radioactive ores are found. Long-term exposure/chronic exposure of low-level radiation (<10 mSv) may result in damage to cells or cancers. The effects of low radiation on the human cell may not be observed for several years until it appears.[11]

SOURCES OF ELECTROMAGNETIC RADIATION

Ionizing radiation

Naturally, >60 radioactive materials are found in air, soil, and water. Approximately 80% of the annual dose of radiation that a human receives are naturally occurring terrestrial and cosmic radiation sources.[12] The human also exposed into human-made EMR sources ranging from chernobyl accident, nuclear power production, atmospheric nuclear testing, diagnostic medical, etc. Globally, natural exposure to radiation by a human is 2.4 mSv/year and medical exposure adds approximately 0.4 mSv/year.[13]

Nonionizing radiation

NIR is low-frequency radiation, and it can be from both natural and man-made sources. Sun is the classical example for the natural source of NIR which emits UV radiation continuously. In general, we are surrounded by NIR from wireless communications devices, computer devices, TV, hand phone/cell phone transmissions, radio and emissions from thunderstorm. The most common source for NIR is transmission lines (50–60 Hz), computer monitor (60–90 Hz), amplitude modulation radio transmissions (530–1600 KHz), lightning storm/thunderstorms (30–300 MHz), frequency modulation radio transmission (88–108 MHz), TV transmissions (50–700 MHz), hand phones (850 MHz-2.4 GHz), wireless data 2.4–5 GHz, and microwave ovens (2.5 GHz).[14]

PHYSIOLOGICAL EFFECT OF ELECTROMAGNETIC RADIATION

EMR is hazardous to all living organisms because its effects are latent, painless, and cumulative. The recipient cannot sense any radiation damage that is happening around them, and symptoms may take up to several days to years to develop.

Physiological effect of ionizing radiation

At frequency above the upper end of the visible light spectrum which is starting with UV radiation, the photon energy of ionizing radiation is sufficient enough to cause ionization damage to human body tissue.[15] Overexposure to ionizing radiation can cause burns/blisters due to the heating effect of radiation, and prolonged exposure may cause chemical changes to the skin.[16] This is very dangerous as ionization cause DNA mutation and the possible formation of tumorous cells in the body. Exposure to radiation with higher frequencies such as X-rays will cause increased damage due to a greater photon energy of the radiation, and it will penetrate deeper in our body with more complicated and serious consequences.[17]

Physiological effect of nonionizing radiation

The photon energies of the NIR poses frequency that is too weak to break atomic bonds and thereby it does not cause any ionization effect directly in a biological system. NIR encompass the long wavelength (>100 nm), low photon energy (<12.4 eV) portion of the EMS, from 1 Hz to 3×10^{15} Hz. It has the ability to penetrate into the human body and causes subsequent health effects, and the effect on health is depends on frequency. High-power densities of NIR can lead to potential health hazards such as headache, fatigue, cancer, and Alzheimer's and Parkinson's disease.[18] NIR can interact with a biological system by either thermal effects or nonthermal effects. Their effects are classified based on their attribution to deposition of heat or without heat component.

Thermal effects occur when absorption of electromagnetic frequency results in tissue heating. Biological tissues are composed of water and electrically charged particles. Each tissue plays a role and has specific capacity to absorb specific energy based on its characteristics. Energy from EMR ranging in radiofrequency to microwave ranges will cause movement of the charged particles when absorbed by the body. As a result, a local increase in tissue temperature is the noticeable effect. It will cause the denaturation of thermolabile molecules such as proteins, increase blood flow to the area that absorbed the radiation, increase metabolic rate (as a result of increasing body temperature), and tissue damage. The main risk of thermal damage will be in the areas of low vascularity, and the most risky organ is the lens of the eyes, as the eye lenses are inadequate for the exchange of heat.[18,19]

Nonthermal effects of NIR are not intermediated by the heat, but it may cause other changes in the tissue as a result of exposure to the NIR. The effects are mainly due to the direct interaction of microwaves field on molecules or

tissue components. Nonthermal effects are biochemical and electrophysical effects in tissues and can result in changes in the cardiovascular, immune, and nervous systems. Other nonthermal effects are the saturation of dielectric that takes place in proteins and biological molecules affect from microwave fields.[19,20]

Health hazards due to mobile phone radiation

Hand/mobile phones have become an integral part of life. Mobile phones are communicated by transmitting radiofrequency waves which are operating at the frequencies between 450 and 2700 MHz, with peak powers in the rage on 0.1–2 watts. Radiofrequency waves are type of EMR and are not ionizing radiation such as X-rays. In the short-term, mobile phones' causing a negligible temperature rise in the brain and long-term effect is not evident.[21] Few effects of mobile phone radiation and mobile phone hazards are discussed below:

- Higher radiofrequency of mobile phones radiation may change brain neural activities, reaction time, and sleep patterns.[22]
- In recent years, most of the global populations, especially preuniversity and university students, were using a smartphone, because of its wider applications. The smartphone is good to use in many ways, and at the same time, it also has disadvantages such as personal attention, social nuisance, reduction in work efficacy, psychological addiction, and neurobiological illness.[23] Smartphone addiction among college studies is about 25%, and it is progressively increasing every year.[24] Smartphone also causes "nomophobia" (no-mobile-phone-phobia), is often fuelled by an Internet addiction disorder or Internet overuse problem. The sings of mobile phone addictions are constantly checking the phone for no reason, waking up in the middle of the night to check mobile and communication updates; feeling anxious or restless without a phone, delay in a professional performance as a result of prolonged phone activities, and distracted with smart applications.[25]
- The withdrawal from the mobile network may increase the anger, irritability, depression, restlessness, and tension which may reduce work efficacy and alter the physiological behavior.[26]

HEALTH HAZARDS DUE TO ELECTROMAGNETIC RADIATION

In our daily life, we are surrounded by EMR; they are emitted to the environment from radio, TV, medical diagnostic, and communication devices such as cell phones and also Wi-Fi routers. Radiation from cell phone and Wi-Fi is the radiation that we encountered the most in our life, and this resulted in increased human exposure to EMR and health risks. Sarı *et al*., reported that low-level exposure to EMR might cause a wide range of health effects in humans, including effects on reproductive and cardiovascular systems, changes in hormone levels, behavioral changes, headaches and also increase the risk of tumor progression.[27]

Cancer risk

Exposure to EMR may increase the cancer risk in human. The World Health Organization reported that the population exposed to radiation had a significant increase in cancer risk at doses >100 mSv. Even lower dose exposure (between 50 and 100 mSv) to children's for medical purposes (pediatric computed tomography) also potentially increases the risk of cancer.[28]

The scientific studies have been showed that long-term use of the wireless device increases the risk of cancer. The International Agency Research on Cancer categorized radiofrequency radiation in the frequency range from 30 kHz to 300 GHz to be a Group 2B carcinogen (a "possible" human carcinogen) with limited evidence.[29] Later, a study had been conducted by Morgan *et al*. and considered CERENAT, a French national study which provides a notable addition to the literature evaluating the usage of mobile phones and risk of brain tumors. This finding has shown that use of mobile phones for a decade or longer may increase the risk of glioma.[30,31] Yang *et al*. also studied the potential association between use of mobile phone and subsequent glioma risk and reported that, long-term mobile phone use might increase the risk of glioma (odds ratio = 1.44, 95% confidence interval = 1.08–1.91).[32] In CERENAT, exposure to radiofrequency EMR from Digitally Enhanced Cordless Telephones (DECTs) was not evaluated, and if exposures to DECT phones could have been taken into account, it will be likely higher the risk of glioma from mobile phone use in CERENAT that published. Hence, this study later conclude that radiofrequency fields should be classified as Group 2A ("probable human carcinogen") under the criteria used by IRAC.[31]

Effect on reproduction system

EMR exposure is associated with reducing sperm count, concentration and motility, as well as altered cell structure and causing DNA damage.[33] In rats, EMR (Wi-Fi devices) exposure increase in serum 8-hydroxy-2'-deoxyguanosine levels, as a marker of DNA oxidative damage and decreased the levels of glutathione peroxidase, catalase, sperm count, and weight of seminal vesicle.[34,35] De Iuliis

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 Cε, 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
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