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Genotoxic Effects of Radiofrequency-Electromagnetic Fields

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ABSTRACT

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Introduction

Radiation is energy emission in the form of electromagnetic waves emitted from the solar system and natural resources on earth. The currents produced by the elementary particles formed by the electric current create the magnetic field. Earth's surface is under the influence of the geomagnetic field emanating from the sun. However, the outer liquid also has a magnetic field created as a result of heat transfer in the core. Therefore, all living organisms on earth live under the influence of electromagnetic fields (EMF). Today, besides these natural energy resources, rapidly developing technological developments provide most of the convenience in our lives and expose people to artificial electromagnetic fields. However, man's magnetic field is also under the influence of other natural and artificial magnetic fields around him. In particular, by ionizing radiation, which carries enough energy to break down the genetic material, die cells as a result of DNA damaging, and other diseases, especially cancer, can develop as a result of tissue damage.

Electromagnetic Fields in Our Lives

Today, apart from natural geomagnetic fields, radiation is emitted from many technological devices. The spectrum of these fields includes many different types of radiation, from subatomic radiation such as gamma and X-rays to radio waves, depending on their wavelengths. Though, as a result of the rapid increase of technological growth, the duration and amount of exposure to EMF is also steadily increasing. On the other hand, wireless gadgets such as computers, smartphones and medical radiological devices have become a necessity for humans. Almost everyone is exposed to radiofrequency electromagnetic fields (RF-EMF) from cell phone and base station antennas or other sources. Thus, the damage caused by the radiation to the environment affects living organisms even many kilometres away unlimitedly. All organisms in the world live under the influence of these negative environmental changes and a large part of the world population is exposed to radiofrequency (RF) radiation for a long time in their daily lives. So, though we are not aware of it, our organs and tissues are constantly exposed to radiation. Therefore, radiation adversely affects human, animal and plant health and disrupts the environment and ecological balance. An example of negative effects, radiation can cause genetic changes in the body (Figure 1).

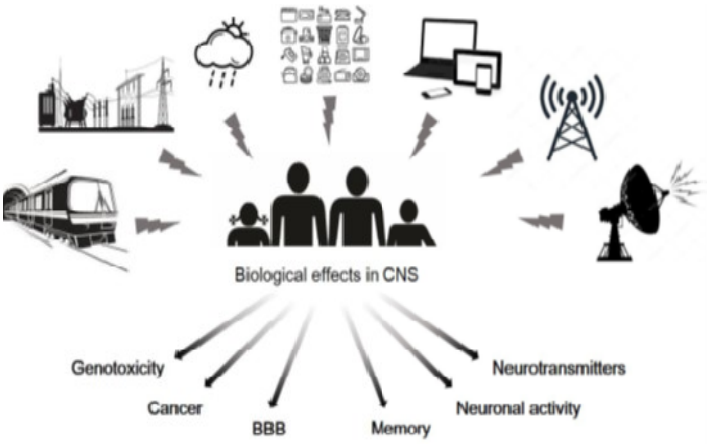

Figure 1. Schematic summary of the possible biological effects of EMF waves (1).

Radiation is divided into ionizing and non-ionizing. Ionizing radiations cause electron loss or gain in an atom or group of atoms in the medium they pass through. Thus, positively or

negatively charged ions are formed. High energy X, gamma, ultraviolet and some visible rays in the ionized region of the electromagnetic spectrum can be counted. Since gamma rays, X rays and ultraviolet rays can ionize the molecules in living things more, they can easily disrupt the chemical structure of tissues, cells and DNA molecules in living organisms. Therefore, they can be very dangerous and deadly to living things. The energy of the waves in the non-ionizing region of the electromagnetic spectrum is low and the energy levels are insufficient for the ionization of molecules. Electricity, radio and TV waves, microwaves, and infrared rays are not ionizing because they have low energy. Waves emitted from electronic devices (cell phones, computers, microwave ovens, etc.) are absorbed by the human and animal body. The amount of energy absorbed by the unit biological tissue mass per unit time is called the specific absorption rate (SAR), and its unit is W/kg.

Risks of Electromagnetic Fields on Living Things

Depending on the structure of the tissues and organs, the radiation must reach a certain threshold dose for the effect to occur. Radiation levels below the threshold dose are not effective. Depending on the structure of the tissues and organs, the radiation must reach a certain threshold dose. The effects of small doses of waves are negligible. However, the clinical effects of waves above a certain threshold may increase. High dose waves can cause cell death in tissues. Damages in the cell may increase the risk of cancer and hereditary damage after a while, and somatic effects in people exposed to radiation may cause cancer to appear years later. There is much research on the effects of RF fields. In vitro and in vivo studies on rats, plants and different tissues of humans; suggests that the RF fields are not genotoxic and the fact that harmful effect is due to the heat effect. The contradictory results on this issue have brought about discussions. Therefore, there are still concerns about the potential adverse effects of RFR on human health. A good understanding of the biological effects of RF radiation will protect against potential damages. Due to these uncertainties, with the electromagnetic field project of the World Health Organization, experimental and modelling studies on the biological effects of RF radiation have been accelerated. In 2011, the International Agency for Research on Cancer decided that RF-EMR waves could be potentially carcinogenic to humans (2). Considering that almost everyone, including young children, uses mobile phones in addition to other technological devices, the danger of electromagnetic waves has increased social interest.

Genotoxic Effects of EMF

In addition to stimulating apoptosis and changes in ion channels, RF-EMF waves also have a potential effect on genetic material. The radiation absorbed by organisms causes the ionization of target molecules. In particular, biological damage may occur as a result of stimulation/ionization of atoms and disruption of molecular structures while ionizing radiation passes through tissue. As a result of ionization in the cell, electron increases and free electrons cause damage, especially in macromolecules and DNA. Free electrons move directly or indirectly. Free electrons directly affect the phosphodiester or H-bonds of DNA. As a result, the phosphodiester bonds of DNA in the cell are broken, single or double-stranded breakages and chemical toxins increase. DNA double-strand breaks are the most relevant biologic damage induced by ionizing radiation (3,4).

There are no cells that are resistant to radiation. The nucleus of the cell and especially the chromosomes in dividing cells are very sensitive to radiation. One of the most important effects of radiation on the cell is to suppress cell growth. In particular, growth is impaired in cells exposed to radiation during cell division (mitosis). Consequently, cells with a high division rate are more sensitive to radiation. DNA damage in somatic cells can lead to cancer development or cell death. Cell death can occur as a result of breaking down DNA because ionizing radiation has enough energy to break down the cell's genetic material. Thus, tissues are damaged and cancer development may be triggered. DNA damage caused by radiation in cells is repaired by metabolic repair processes. If the breaks in DNA as a result of DNA damage caused by radiation in cells are not too large, they can be repaired by metabolic repair processes. Still, errors may occur during this repair. Chromosomes containing different genetic codes and information may also occur. In the cell, the released electrons interact with water molecules, indirectly causing the water to be reactively divided into two parts. Free radicals carry an electron that is not electrically shared in their orbits. Free radicals can cause genetic damage in DNA such as nucleotide changes, double and single-strand breaks. Radiation can cause chromosomes to break, stick together and rearrange. All these changes can lead to mutations or even further, the death of the cell. However, in addition to ionizing radiation, extracellular genotoxic chemicals and intracellular oxidative metabolic residues can also create stress in cells during DNA replication and cell division. Damage may occur during DNA replication under such environmental stress conditions.

To date, conflicting results have been reported regarding the genotoxic effects of RF-EMF waves on genetic material. It has been reported that the energy of low EM fields is not sufficient to break the chemical bonds of DNA, but the increase in exposure time is effective on the formation of oxygen radicals and the disruptions in the DNA repair process. The absorption of microwaves can cause significant local warming in cells. For example, an increase in temperature has been observed in cells in culture media exposed to waves of high SAR levels. However, there is evidence that reactive oxygen species are formed in cells indirectly and experimentally exposed to RF-EMF waves. Free oxygen radicals can create nucleotide entries in DNA as well as bind cellular components to DNA bases (5). The frequency of polymorphisms observed in DNA repair mechanism genes in children with acute leukaemia living close to high energy lines reveals the effect of this energy on the repair process. Significant evidence has been reported that genotoxic

effects occur in various cell types when exposed to RF-EMF waves (6-10). Here, it has been reported that cells exposed to RF-EMF waves (1.800 MHz, SAR 2 W/kg) cause oxidative damage in mitochondrial DNA, DNA breaks in neurons and DNA breaks in amniotic cells (6,10). Similarly, the damage has been reported in lymphocytes exposed to various RF-EMF waves (8). However, exposure to RF-EMF waves is known to cause chromosome imbalance, changes in gene expression, and gene mutations. Such deleterious genetic effects have also been reported in neurons, blood lymphocytes, sperm, red blood cells, epithelial cells, hematopoietic tissue, lung cells, and bone marrow (1,11,12). It has been found that exposure to RF-EMF radiation also increases chromosome numerical aberrations (6,13). It has also been reported that increased chromosome separation in mouse oocytes exposed to EM and increased DNA fragmentation and apoptosis in fly egg cells (14,15). However, increased DNA breaks have been reported in the blastomeres of embryos of pregnant mice exposed to a frequency of 50 Hz, and a decrease in the number of blastocysts has been reported (16). Genetic damages to sex cells can lead to persistent genetic diseases in subsequent generations.

Today, X-ray devices used for medical diagnosis have become one of the largest sources of radiation. These radiological procedures used for diagnosis constitute an important part of ionizing radiation. During these processes, the human body is visibly or invisibly affected by X-rays. As a matter of fact, X-rays have effects of disrupting the structure and biochemical activities of DNA, RNA, proteins and enzymes that are vital in the organism (17). Many studies on this subject have revealed that radiation has suppressive and mutational effects on DNA synthesis. These effects can cause serious damage to the cell as well as DNA and chromosome damage. In a recent study, chromosome damage was investigated in patients with X-ray angiography and personnel working in radiological procedures (18). Our findings showed that the beams used in interventional radiological procedures caused chromosomal damage and the rate of chromosomal abnormalities (CAs) increased significantly in patients after the procedure and this damage increased with the amount of radiation dose. Therefore, the radiation dose to be given to the patient should be chosen carefully. Besides, our findings showed that the frequency of CA is significantly higher in personnel working in radiological procedures. This reveals that interventional cardiologists are exposed to high radiation exposure. For this reason, we can say that the personnel working in radiological procedures (physician, health technician and nurse) are very likely to get diseases after years because they are exposed to low doses but long-term X-rays. Therefore, both the potential risks and safety of exposure to medical radiological devices must be continuously monitored. Furthermore, the fact that chromatid and chromosome breaks are very common among structural CAs in our findings suggests that they may be the cause of malignancy. Because, there are many cancer genes, tumour suppressor genes, enzyme genes involved in DNA repair and important genes or candidate genes responsible forapoptosis on these chromosomes. All this information shows that patients are more susceptible to DNA damage and inappropriate radiological examinations should be avoided. Therefore, X-ray and other diagnostic imaging techniques should not be applied unless necessary, and physicians and patients should be more careful in this regard.

It has been reported that RF-EMR waves emitted from wireless communication device mobile phones have a genotoxic effect on human and mammalian cells (6,19). In a recent study; The effects of 900 and 1800 MHz cell phone frequencies on human chromosomes were investigated in amniotic cell cultures (6). Here, it has been reported that chromosome packing delays, damage and breaks occur in amniotic cells exposed to 900 and 1800 MHz every day at 3, 6 and 12 hours for twelve days. However, it was found that the frequency of 1800 MHz caused more CAs than 900 MHz, and the amount of damage increased with increasing usage time. These results confirm that GSM-like RF-EMR causes direct genotoxic effects in human in vitro cultures and has adverse effects on human chromosomes, and these effects increase in parallel with exposure time. This shows us that the mobile phone carries a risk for human health and these genetic damages can cause cancer. Therefore, necessary precautions should be taken for these harmful effects of mobile phones. Among these measures, the periods of mobile phone use should be kept short, especially the exposure of developing children and infants to mobile phones should be prevented, and avoiding excessive use of mobile phones may be one of the precautions against cancer. However, in order to evaluate it in more detail, the effects of mobile phones with environmental mutagens and/or carcinogens should be considered in subsequent researches.

Conclusion

Today, in parallel with the increasing technological developments, the demand of the society for electronic devices and phones and the frequency ranges of electronic devices are constantly increasing. Waves emitted from electronic devices are absorbed by human and animal bodies. Especially, the use of phones by contact with our body and the increase in usage time affects not only adults but also young children. Therefore, there is increasing concern in society about the negative biological effects of EM waves emitted from phones and other electronic devices. Results from all studies show that RF-EMF waves may be carcinogenic due to their genotoxic effect. Because cancer is a disease that occurs as a result of genetic damage. Considering these negative and harmful effects, regulations following international standards regarding the use of electronic devices should be made and society should be made aware of the risks.

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