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Radiofrequency Electromagnetic Radiation from Cell Phones and Human Genetic Defects: Any link?

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ABSTRACT

Cell phones are defined as devices emitting radiofrequency electromagnetic waves (RF-EMW). These waves transmit signals from the cell phones to the base stations and antennas. The number of cell phone users in the world has gone up to 6 billion being the most effective communication tools all over the world and this increase is expected to continue as such, the amount of radiofrequency electromagnetic fields (RF-EMF) exposure will continue to increase steadily. The rise in cell phone usage has raised health concerns about electromagnetic field exposure, which could potentially damage genetic material of the cell. Damage to somatic DNA can lead to cancer or cell death, while germ cell damage can cause genetic damage in future generations. This review paper looks at genetic disorders, the evolution of cell phones and its related technological advancements, the roles of radiofrequency electromagnetic radiation from cell phones in genetic damages and the possible mechanisms. Researches has shown, both epidemiological and experimental, in non-human animals and in humans, some of which had shown causative relationship between exposure to mobile phones and harmful biological effects in humans. Deletions, inversion and dicentric chromosomes alone are reliable indicators of mobile phone RFR on fetal chromosomes. Several studies reported that RF-EMF exposure from cell phones caused DNA strand breaks, chromatin conformation and condensation, increased damage through disturbances in spindle function. The formation of micronuclei and reactive oxygen species are some of the mechanisms reported with which genetic damage is caused following exposure to RF-EMF from cell phones.

Keywords: cell phone, radiofrequency, electromagnetic radiation, genetic defects

INTRODUCTION

Cell phones have become the most effective communication tools globally[1]. The number of cell phone users in the world has increased to 6 billion in 2013 corresponding to a total rate of about 93.1% per 100 inhabitants [2]. It is convenient for cell phones to be used everywhere because it does not use the physical cable or wire needed for the communication purposes. Their demand for the electromagnetic radiation for receiving and transferring the data in the air, depends on network or a sound data [3]. The global increase in cell phone users has raised health concerns due to potential risks associated with exposure to electromagnetic waves produced by it.. Given the vast number of cell phone users, a negative effect could have huge public health implication [4]. The potential effects of RF radiation on the genetic material of cells are considered significant since damage to the DNA of somatic cells might be connected to cancer formation or cell death, while damage to germ cells can lead to genetic damage in the next and following generations [5]. There has been much concern that the radiation from mobile phones may lead to numerous pathologies such as cancer, male infertility, hearing impairment, Alzheimer's disease, Parkinson's disease, asthma, hypertension, leukemia, rheumatoid arthritis, birth abnormalities, and so on [6 -12]. Aside the effect of RF radiation on DNA damage, the deep penetration or RF radiation from cell phones may produce overproduction of free radicals, notably reactive oxygen species (ROS), thereby inducing adverse effects in living cells [13]. This paper will look at genetic disorders (types and causes), the evolution of cell phones and its related technological advancements, the roles of radiofrequency electromagnegnetic radiation from cell phones in genetic damages and the possible mechanisms.

Genetic disorders

A genetic disorder is a health challenge caused by one or more abnormalities in the genome [14]. The genetic abnormality can range from minute to major changes, such as from a discrete mutation in a single base in the DNA of a single gene to a gross chromosomal abnormality which involves the addition or subtraction of an entire chromosome or set of chromosomes [15]. Some individual inherit genetic disorders from the parents, while some can be due to acquired changes or mutations in a preexisting gene or group of genes. Genetic mutations can occur either randomly or as aresult of some environmental exposure[14]. The mutation responsible can occur spontaneously before embryonic development (a *de novo* mutation), or it can be inherited from the two parents who are carriers of a defective gene (autosomal recessive inheritance) or from a parent with the disorder (autosomal dominant inheritance).

A single-gene disorder (or monogenic disorder) is the result of a single mutated gene. Single-gene disorders can be passed on to successive generations in several ways. Genomic imprinting and uniparental disomy, however, may affect inheritance patterns [16]. The distinctions between recessive and dominant types are not "hard and fast"; nevertheless, the distinctions between autosomal and X-linked types are. Sickle-cell anemia is considered a recessive disorder, however heterozygous carriers have enhanced resistance to malaria in early life, which might be classified as a similar dominant condition [17]. The majority of congenital metabolic abnormalities, also known as inborn errors of metabolism, are caused by single gene deficiencies. Many such single-gene abnormalities can reduce the fitness of affected persons and are thus prevalent in the population in lower numbers than what would be expected based on basic probabilistic calculations [18].

Genetic illnesses can also be complicated, multifactorial, or polygenic, which means they are caused by the interactions of numerous genes, as well as lifestyle and environmental variables. Although complicated illnesses frequently cluster in families, they do not have a clear pattern of inheritance. This makes it impossible to predict a person's likelihood of inheriting or passing on these diseases. Complex diseases are particularly challenging to investigate and treat since most of the underlying causes have yet to be found. Several methodological techniques can be used in studies to discover genotype-phenotype relationships in complicated diseases.

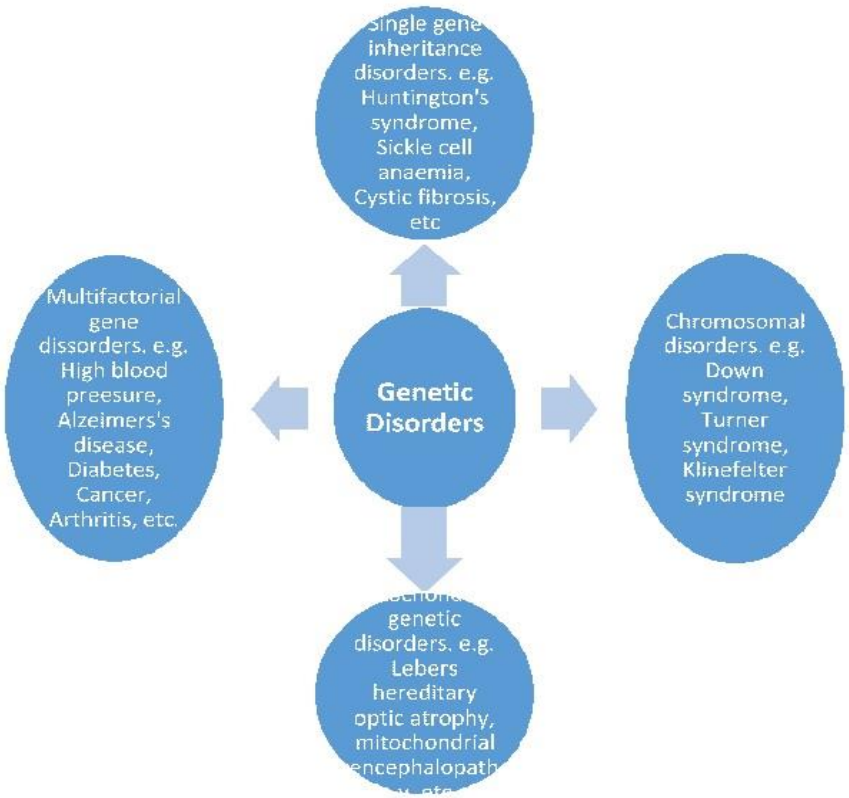

Figure 1: Types of genetic disorders

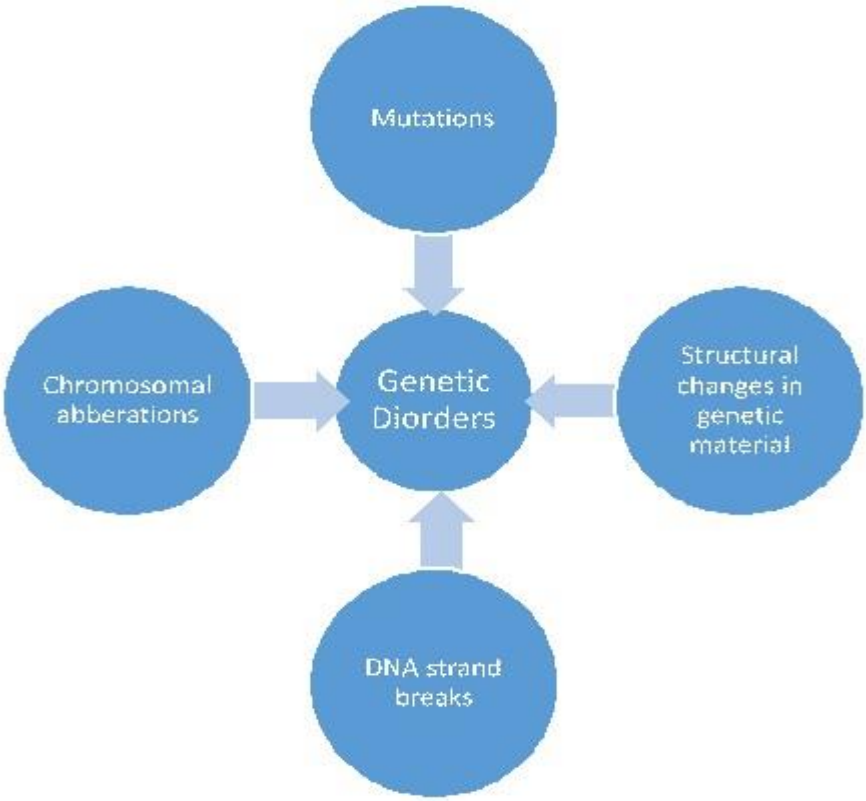

Figure 2: Causes of Genetic disorders

A chromosomal disorder, anomaly, aberration, or mutation is as a result of a missing, extra, or irregular portion of chromosomal DNA [14] . It might result from a typical number of chromosomes or a structural defect in one or more chromosomes. Previously, the term "chromosomal mutation" was used only to refer to a change in a chromosomal section that involved many genes [19]. The term "karyotype" refers to an individual's complete set of chromosomes, which may be compared to the species' "normal" karyotype via genetic testing. This method can be used to discover or confirm chromosomal abnormalities. Chromosome abnormalities are mainly caused by an error in cell division after meiosis or mitosis. There are several forms of chromosomal abnormalities. They can be divided into two categories: numerical and structural abnormalities.

Numerical chromosomal disorder called aneuploidy (an abnormal number of chromosomes) occurs when an individual either is missing a chromosome from a pair (monosomy) or has more than two chromosomes of a pair (trisomy, tetrasomy, etc.) [19]. Increased aneuploidy is often associated with increased DNA damage in spermatozoa. Structural abnormalities can occur when the chromosome's structure is altered, which could take several forms such as deletions, duplications, translocations, inversion, insertion, etc [20].

Most chromosomal abnormalities occur as a distortion in the egg cell or sperm, therefore the abnormality is present in all cells of the body. Some abnormalities, however, can occur after conception, resulting in Mosaicism (wherein some cells have the abnormality and some do not). Chromosome abnormalities can be inherited from a parent or developed *de novo*. This is why chromosomal testing on parents are frequently undertaken when a child is discovered to have an abnormality. If the parents do not have the anomaly, it was not inherited; nonetheless, it may be passed down to future generations. DNA repair effectively removes DNA damage during mammalian gametogenesis's mitotic and meiotic cell divisions [18]. However, the ability to repair DNA damage reduces significantly in the final stages of spermatogenesis as haploid spermatids undergo significant nuclear chromatin remodeling into highly compacted sperm nuclei and studies found that the last few weeks of sperm development before conception are particularly vulnerable to the buildup of sperm DNA damage [21]. Such sperm DNA damage can be transported unrepaired to the egg, where it is removed by the maternal repair machinery. However, failings in maternal DNA repair of sperm DNA damage can produce zygotes with chromosomal structural abnormalities.

Genetic damage can be verified by means of comet assays, micronuclei tests, and chromosome analysis [22]. The comet assay analyzes single- and double-strand DNA breaks, which occur at various stages of the cell division cycle. The micronuclei test detects chromosomal damage caused by either DNA damage, such as double-strand breaks, or disruptions in spindle activity during cell division. Damaged or mutated chromosomes can be counted under the microscope after applying a specific dye.

Cell Phones

The advancement of metal-oxide-semiconductor (MOS) large-scale integration (LSI) technology, information theory, and cellular networking enabled the creation of low-cost mobile communications [23]. In 1973, John F. Mitchell [24] and Martin Cooper of Motorola exhibited the first portable mobile phone, which weighed around 2 kg [25]. The DynaTAC 8000x was the first commercially available handheld mobile phone in 1983, and worldwide mobile phone subscriptions increased to more than seven billion between 1983 and 2014, enough to give one for every person on the planet [26]. Wireless devices, such as mobile phones, are widely used across the world, whether for personal or professional purposes, and exposure to radio-frequency radiation (RFR) is frequent, particularly in public places [27,28]. Mobile phones and tablets have become the most effective communication tools, particularly in urban areas [1]. In recent years, the general population has grown more exposure to radiofrequency (RF) fields from mobile phones and other communication gadgets. In a world of 7.4 billion people, there are already 5 billion mobile phone users [1].

Cell phones are described as devices that transmit radiofrequency electromagnetic waves (RF-EMW). These waves carry signals from mobile phones to base stations and antennas. The frequency of such waves spans between 800 and

2,200 MHz. However, there is still a risk to human health since our bodies may function as antennas, absorbing these waves and converting them to eddy currents [29] . The mechanics of a mobile phone function in such a manner that the sound wave produced by the speaker passes via a transmitter, which turns it into a sine wave.

This sine wave then travels to the antenna, which sends it out into space. The average power usage of the transmitter is 0.75-1 W, with a maximum of 2 W [29]. The force of the electric sine wave traveling through the transmitter circuit generates an electromagnetic field. As the electric current oscillates back and forth, these electromagnetic fields continue to expand and collapse, producing electromagnetic radiation [30]. Cell phones typically function at frequencies ranging from 850 to 1,800 MHz, and the radiation is absorbed by human body tissues and organs, resulting in radiofrequency signal and/or resonant absorption [31].

Digital cellular networks first appeared in the 1990s, thanks to the widespread adoption of MOSFET-based RF power amplifiers (power MOSFET and LDMOS) and RF circuits (RF CMOS) [30, 32], which led to the introduction of digital signal processing in wireless communications [23]. Radiolinja introduced second-generation (2G) digital cellular technology in Finland in 1991, based on the GSM (Global System of Mobile Communication) standard. This prompted competition in the market, as new operators took on the established 1G network operators. The GSM standard is a European project presented by the CEPT (Conférence Européenne des Postes et Telecommunications).

The Franco-German R&D cooperation created technological viability, and in 1987, 13 European nations signed a Memorandum of Understanding, agreeing to develop a commercial service by 1991. The initial version of the GSM (=2G) standard had 6.000 pieces of technical documentation. In 2018, the GSM was used by over 5 billion people in over 220 countries [26]. The GSM (2G) has evolved into 3G, 4G and 5G.

The rising use of mobile phones has raised concerns about health safety, particularly pediatric and adult malignancies. While it is evident that high intensity electromagnetic waves, such as X-rays, have substantial biological impacts due to ionizing damage, there have been questions over whether radiation from cell phones has a negative impact on biological systems. Mobile phones and tablets generate electromagnetic radiation in the microwave range (850-1800) [1]. Collected evidence suggests that the frequency generated by mobile phones or base stations may have an impact on people's health [33].

There is a substantial corpus of epidemiological and experimental study on nonhuman animals and humans. Some of these studies find no clear causal association between mobile phone exposure and negative health consequences in people. This is sometimes referred to as the balance of evidence indicating that mobile phones do not cause harm to humans, despite the fact that a considerable number of individual research either suggest or are inconclusive on this point. On May 31, 2011, the World Health Organization said that mobile phone usage may possibly represent a long-term health risk [34] and classified mobile phone radiation as "possibly carcinogenic to humans" after a team of scientists examined studies on mobile phone safety.[35, 36 37]. The mobile phone is in category 2B, which ranks it alongside coffee and other possibly carcinogenic substances [37, 38].

Carcinogenecity

Since the International Agency for Research on Cancer (IARC) classified RFR emitted by cell phones and other WTDs as a Group 2B (‘possible’) human carcinogen in 2011 [39] , analyses of the large international Interphone study, a series of studies by the Hardell group in Sweden, and the French CERENAT case-control studies have indicated increased risks of brain tumors, especially with ipsilateral use [40]. The largest case control studies on cell phone exposure and glioma and acoustic neuroma showed significantly elevated risks that tended to increase with increasing latency, increasing cumulative duration of use, ipsilateral phone use, and earlier age at first exposure [40]. This is a reversal of the prior position that cancer was unlikely to be caused by cellular phones or their base stations and that reviews had found no convincing evidence for other health effects. Possible effects of RF on DNA or chromosome structure in somatic cells are considered to be very important as these changes could be associated with cell death or, possibly, with the development of cancer.

A study by Ramazzini Institute has evaluated lifespan environmental exposure of rodents to RFR, as generated by 1.8 GHz GSM antennae of cell phone radio base stations [41]. Male rats exposed to the highest dose showed statistically significant increases in heart Schwannomas, and both male and female mice showed heart Schwan cell hyperplasia, despite exposures being 60–6,000 times lower than those in the NTP trial [41]. There was also a non-statistically significant rise in malignant glial tumors in female rodents. The results of the NTP study on near field exposure are supported and compatible with these findings with far field exposure to RFR. Both found that RFR-exposed Sprague-Dawley rats had higher rates of brain and heart cancers, which are the same histological kind of tumors seen in certain epidemiological research on mobile phone users.

DNA damage indicators in ear canal hair follicle cells were shown to be higher in the RFR exposure groups than in the control participants in a study including four groups of men, one of whom did not use a mobile phone. Furthermore, the longer the exposure period per day, the more DNA damage occurred [42]. Many claim that because RFR lacks the energy to directly damage DNA, it cannot be carcinogenic [43-46]. Even though RFR was not genotoxic, some of these researchers noted that it might exacerbate the cytogenetic harm caused by other chemical or physical agents.

While some studies indicated that cells exposed to RF energy suffered significantly more damage than unexposed and/or sham-exposed control cells, others did not[47]. Unfortunately, in evaluating the evidence, these authors neglected to take into account baseline DNA status or the fact that genotoxicity has been poorly predicted using tissue culture studies [48]. Additionally, funding, a significant source of bias in this area of research, was not taken into account [49,50].

Oncogenes and tumor suppressor genes are clustered around recombination hotspots or fragile sites in the genome because double-strand break is the common initial step in translocation, deletion, and gene amplification. Some studies have suggested that RF-fields can still affect DNA. Ros-Llior *et al* [51] examined the effect of cell phones on the frequency of micronucleus in oral mucosal cells obtained from humans and found no genotoxicity in association with RF-EMR. However, it stated that avoiding excessive cell phone use should be considered as one of the potential precautions against cancer [52-54]. Therefore, it may be considered that the expression of fragile sites could be an indicator of chromosomal instability within the genome of cancers.

Advances in technology and its implication on human health

Rapid advancements in RFR-related technologies seem to limit the amount of data that can be collected on human RFR exposure to specific frequencies and modulations and related health outcomes over the course of the technology's lifespan. Epidemiological studies with adequate statistical power must be based on large numbers of participants with sufficient latency and intensity of exposure to specific technologies; therefore, a lack of epidemiological evidence does not necessarily indicate an absence of effect, but rather an inability to study an exposure for the length of time necessary, with an adequate sample size, and unexposed comparators, to draw definitive conclusions.

Frequency bands for 5G are divided into two distinct frequency ranges: Frequency Range 1 (FR1) includes sub-6GHz frequency bands, some of which are bands traditionally used by previous standards but have been extended to cover potential new spectrum offerings from 410 MHz to 7125 MHz. The telecom industry's fifth generation (5G) wireless service will require the placement of many times more small antennae/cell towers near all service recipients because solid structures, rain, and foliage block the associated millimeter wave RFR [54].

Bands in FR2 are generally of millimeter wave length, these have a shorter range but a larger potential bandwidth than bands in the FR1. Large arrays of directional, steerable, beam-forming antennas are used in 5G technology, which is being developed and implemented at a greater power than earlier technologies. 5G will function and interact with existing frequencies and modulations, such as 3G and 4G, to enable a variety of devices that are constantly being developed for the "internet of things," autonomous cars, and other applications [54]. In many densely populated cities, new 5G technology is being introduced; however, the possible long-term health or environmental

effects have not been assessed and are not being monitored.

Although it may have systemic effects, 5G's higher frequency (shorter wavelength) radiation does not penetrate the body as deeply as frequencies from older technologies [56,57]. The scope and magnitude of 5G technologies' potential impacts are not well understood, despite the fact that millimeter wavelength exposure has been linked to important biological outcomes, such as oxidative stress and altered gene expression, effects on skin, and systemic effects like immune function [57]. *In vivo* studies that show resonance with human sweat ducts [56], acceleration of bacterial and viral replication, and other endpoints suggest that this range of frequencies may have both novel and more widely known biological impacts, and emphasize the need for research before population-wide continuous exposures.

Biophysical parameters of RF-EMF

By measuring the rate of radiation absorption, the biophysical parameters characterize the biological and physical elements that affect cellular radiosensitivity to RF-EMF exposure. Theoretically, in order to trigger a biological reaction, the electromagnetic field must enter the exposed biological system and create internal electromagnetic fields. However, incident field parameters (such as intensity and power density), zone exposure, object shape, geometry, and orientation, as well as radiation configuration (such as the object's distance from the RFR source), all affect the penetration depth or RF radiation absorption [58]. By raising the levels of ROS, which have been linked to DNA damage, these factors either directly or indirectly contribute to the creation of free radicals.

One of the major issues with many diseases is DNA damage. But how might DNA be harmed by such low frequency radiofrequency radiation is the issue. It is difficult to address this issue, although it is generally accepted that a radiofrequency electromagnetic field is categorized as non-ionizing radiation since its photons lack the energy necessary to directly ionize biological molecules or break chemical bonds. Since it is widely acknowledged that EMF radiation alone cannot cause direct DNA damage, indirect explanations for EMF-induced DNA damage, such as the free radical theory, have been put forth [59,60].

Since mobile phones radiate radiation to adjacent relay base stations or antennas, they are equally to blame for health impacts as their transmission towers. According to a study [58], our bodies function as antennas, absorbing radiation and transforming it into alternating eddy currents. Radiation from cell phones is produced in the transmitter and sent out as radio waves via the antenna [61,62]. The SAR is a standardized measurement used to quantify the effect of this RF-EMF on the human body. The rate of energy absorbed by or deposited per unit mass per unit time is the SAR and E-filed can be calculated by-SARðW=KgÞ ¼ σE2=ρ, where rho (ρ) is the liquid's density and sigma (σ) is its conductivity. 1 g and 10 g mass averaged SAR values are the measured E-field values and SAR distribution, respectively. The RF energy is dispersed and attenuated when it passes through bodily tissues when a biological body or tissue is subjected to RF-EMF. The frequency of the radiation and the makeup of the exposed tissue have a significant impact on energy absorption. The depth of penetration is the physics difficulty with regard to EMF exposure. When utilizing electro-magnetic gadgets or making a mobile phone call, the higher absorption rate of radiation from the phone is more absorbed inside the tissue. Despite the above, it has been maintained that the short-term effects of radiofrequency radiation are insufficiently powerful and effective to alter the genome at any level, since the damage may be the consequence of cumulative effects from repeated exposure [61]. However, it is also proposed that the fundamental process of sperm DNA breakage involves oxidative stress.

Effects on Genetic Defects/Damage

Humans are constantly exposed to both natural and artificial sources of ionizing and non-ionizing radiation, such as electric and magnetic forces. Given the surge in genetic problems, one of the main areas of worry is the potential genetic impacts of mobile phone radiation. Since damage to somatic cell DNA can be connected to the development of cancer or cell death, while damage to germ cells can result in genetic damage in the next and following generations, the potential consequences of radiofrequency

radiation on cell genetic material are thought to be quite significant [50].

The findings of a research showed that human chromosomes were significantly impacted by exposure to GSM-like RF-EMR, and that acute non-thermal exposure to 900 MHz and 1800 MHz RF for GSM caused chromosomal damage in human embryonic cells [5]. On the other hand, the comparatively high rate of malignancies implies that non-ionizing radiation has an impact on chromosomal condensation. Additionally, this genetic damage would undoubtedly be a sign of a major health danger. The only accurate markers of mobile phone RFR of fetal chromosomes are deletions, inversions, and dicentric chromosomes. It was determined that mobile phones pose a harm to human health and chromosomes.

Micronuclei, chromosomal damages and genomic instability

One well-known indicator of genotoxic events is micronuclei (MN), whose formation can cause cell death, genomic instability, or the emergence of cancer [63]. Another well-known cause of genomic instability is ionizing radiation [64]. Ionizing radiation exposure in mice may fragment sperm DNA and result in transgenerational genomic instability in the progeny [65]. Delays in the de novo development of genetic changes after several cell generations are known as radiation-induced genomic instability (IGI). Rats' bone marrow and peripheral blood erythrocytes have been utilized to evaluate chromosomal damage caused by micronuclei [66] .

Additionally, it was revealed that following exposure to 10 GHz microwaves, there was a substantial ($P < 0.0004$) increase in the development of micronuclei in blood samples by 52.75% as compared to the control [66] . One accurate way to quantify genotoxic or cytotoxic damages "in vivo" is to monitor the generation of micronuclei [67]. The fundamental mechanism of micronuclei creation is that erythroblasts disrupt the chromosomes in the cytoplasm of early erythrocytes (in the form of micronuclei) and eject their nucleus during the generation of red blood cells (RBCs). The radiofrequency-induced MN are expected to develop by a clastogenic impact because of their tiny size [62]. Induced genomic instability is caused by EMF-induced micronuclei production [62]. Furthermore, exposure to very low frequency electromagnetic fields may cause genomic instability after several generations, according to in vitro research employing neuronal cell lines [68,62].
In a research to check for cytogentic damage in human lymphocytes after RF exposure by mobile phone, it was found that after 15 minutes of exposure to phase modulated RF-EMF signals [69], human lymphocytes had more genetic damage (micronuclei). Another study [46] likewise found that mitomycin-induced mitomycin-induced human lymphocytes have higher levels of genetic damage (micronuclei, DNA strand breaks), which is greatly enhanced by exposure to radiofrequency radiation.

According to other research, human lymphocytes, fibroblasts, and lens epithelial cells' DNA strands were broken by RF-EMF exposure [70,71]. Chromatin conformation and chromatin condensation in human lymphocytes after exposure to RF-EMF from cell phones have been reported by some researchers [72-74], while other researchers have reported increased damage due to spindle function disturbances after exposure to cell phones [76].

RF induced oxidative stress and ROS formation

The generation of reactive oxygen species (ROS) and the resulting elevated oxidative stress may be linked to the association between RF-EMF exposure and potential genetic abnormalities. When there are too many oxidants compared to antioxidants, the natural equilibrium between oxidants and antioxidants is upset, a situation known as oxidative stress. This disorder causes biological harm to cells, tissues, and organs [76]. Oxidative stress may be the primary cause of an increase in chromatin/DNA damage in sperm [77]. On the other hand, oxidative stress due to mobile phone radiation exposure may increase lipid peroxidation and alter the body's antioxidant functions [78].

In addition to causing histopathological changes in various animal organs[79,80], studies have shown that exposure to electromagnetic fields (EMF) raises intracellular levels of reactive oxygen species (ROS), which in turn alter DNA, gene expression, and unsaturated fatty acids [61,81,1]. During pregnancy, ROS affect the embryo's and fetus's organogenesis and brain development [82,83].

There is also evidence that exposure to mobile phones causes DNA breakage and a reduction in sperm motility and viability due to an increase in mitochondrial ROS generation [84]. Therefore, scavenging these very reactive molecules is crucial in defending the cells from free radical assaults with antioxidants.

Furthermore, mobile phone use can have harmful consequences that include alterations in protein kinases and antioxidant enzymes, increased DNA damage, micronuclei production, and genomic instability. According to Oktem *et al*. [85], rats exposed to microwave radiation from a GSM900 mobile phone have higher MDA (malondialdehyde) values, which are biomarkers for lipid peroxidation, while also having lower levels of antioxidant biomarkers like glutathione peroxidase (GSH-Px), catalase (CAT), and superoxide dismutase (SOD). Wistar rats exposed to GSM900 transmissions had pathological skin alterations, such as epidermal atrophy [86].

Another study discovered that the skin of rats has lower levels of antioxidants CAT, SOD, and GSH-Px following their exposure to the microwave radiation from a GSM1900 cell phone. Insufficient antioxidants or a higher rate of DNA damage than repair impede genetic control or protein expression, which can have a variety of harmful effects. Therefore, because ROS/RNS-mediated DNA damage promotes the processes of carcinogenesis start and promotion, the chance of cancer development rises[87,88].

Since mitochondrial DNA, or mtDNA, is ten times more vulnerable to oxidative stress than nDNA, the DNA found in the cell nucleus, damage to this kind of DNA is especially lethal. The reason for this is that mtDNA lacks an efficient repair mechanism and is not shielded by histone proteins [89]. Damage to mitochondria's mtDNA can cause such severe damage that (i) the various respiration processes can no longer operate normally, but more ROS are produced, and (ii) the energy generation will drop below a critical threshold, which will cause the cell to die (apoptosis) [90]. If the apoptotic mechanisms are inhibited, the cell will develop into a cancerous cell [91] and transition from an oxygen-dependent ATP production process in the mitochondria to a non-oxygen enzymatic ATP production process in the cell plasma [92]. The cell will change into a cancerous cell (Ute) if the apoptotic mechanisms are inhibited. At the same time, the energy production process will change from an oxygen-dependent ATP production in the mitochondria to a non-oxygen enzymatic ATP production in the cell plasma [92]. Since anerobic glycolysis produces far fewer ROS/RNS, the oxidative stress situation is defused, making this physiological transition of energy generation a counterregulation by the cell [91]. Energy production is also occasionally altered in healthy cells (during late-stage cell division) to shield exposed chromosomes from ROS and RNS [91]. This fact clarifies the finding that cells can also develop into cancer cells in the absence of damage to the nucleus' DNA (nDNA)[93,94] . It is thus clear why higher ROS/RNS production has a negative effect on health: The damage that results to proteins, lipids, and DNA has a negative impact on health and can lead to degenerative disorders including cancer. Investigations into how RF-EMFs affect free radicals, or ROS/RNS, in biological systems, however, show that: Four hours of 900 MHz exposure causes a reduction in antioxidants and an increase in lipid peroxidation in the plasma (SOD, GSH-Px, catalase) in erythrocytes [95], rats exposed to 900 MHz RF-EMFs (SAR: 0.52 W/kg, 20 min/day, 7 days/week, 1 month) showed increased malondialdehyde (MDA) values (MDA: marker for lipid peroxidation) in their brains [96, 97]. An increased level of ROS in rat lymphocytes can be shown when the rats are exposed with 930 MHz RF-EMFs (SAR: 1.5 W/kg) for 5 or 15 min [98]. Long-term exposure to mobile phone radiofrequency electromagnetic radiation resulted in impaired testicular function linked to elevated oxidative stress[12]. Rats exposed to 900 MHz, 30 min/day, 1 month, SAR: 4 W/kg, had higher levels of ROS and lower levels of antioxidant enzymes in their kidney tissue [86]; pigs exposed to GSM mobile phone signals (890-915 MHz, 12 h/day, 30 days) had higher levels of MDA and lower levels of GSH (glutathione) in their brain tissue [99]; ROS levels are greater in human monocytes and lymphocytes exposed to GSM signals, 1.8 GHz, 2 W/kg, 30 or 45 minutes, than in those not exposed.

CONCLUSION

Advances in RFR-related technologies is on the increase. The range and magnitude of potential impacts of 5G technologies are under-researched, although important biological outcomes have been reported with millimeter wavelength exposure. Avoiding excessive cell phone usage

should be considered as one of the possible precautions against cancer and other genetic defects. Recently, governmental regulation in some countries on RF-EMFs of some devices including cell phones had been introduced to reflect the concern about biological effects generally but not precisely on genotoxicity of RF-EMF. Therefore, it is necessary to apply international standard at the preventive level at least and provide information to the general public in a clear manner.

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