

# BIOLOGICAL EFFECTS OF ELECTROMAGNETIC RADIATION FROM MOBILE PHONES AND MOBILE TOWERS ON HUMANS: A REVIEW

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**Abstract:** Widespread concerns have been raised about the possibility that exposure to the electromagnetic field (EMF) radiation from mobile telephones or their base stations could affect people's health. Such has been the rapid growth of mobile telecommunications that the number of mobile phone users in the world is expected to cross the five billion mark by 2019. These concerns have induced a large volume of research studies on the negative effects of mobile and mobile base stations radiation on the health of humans. However, there are also a large number of counter studies which downplayed any such effects of mobile radiation and stressed on the safety of using these devices. This paper provides a review of such studies which investigated the possible negative effects of EMF radiation on the health of humans while at the same time highlighting some of the studies which found no such effects of the radiation. The aim of the paper is to provide insights into the various health effects that may be caused, especially, by long-term exposure to such radiations and also suggest further research in the field which could provide a clear picture as to the negative effects of EMF radiation, if any, so as to enable regulating agencies to come up with more stringent exposure norms to prevent any effects on a catastrophic scale. And, if no such effects are found, then the public should be made aware so as to allay fears regarding the radiation exposure and the use of such devices.

**Index Terms:** Mobile Phones, Humans, Electromagnetic Field, Radiofrequency, Mobile Base Stations, Specific Absorption Rate, Power Density, Effects.

## I. INTRODUCTION

Wireless technologies are ubiquitous in this modern age and the mobile phones are one of the prodigious and most valuable outputs of this technology. Although the growing dependency on mobile phones is moving at an alarming pace, the biological effects due to the exposure to mobile-phone and mobile-tower radiations have become a subject of intense debate. Since decades, the exponential growth of personal telecommunication devices like Global System for Mobile Communication (GSM) mobile phone has become the issue of discussion. Cell phone frequencies vary according to the system used, ranging around 900MHz to 1800MHz (GSM) and 2200MHz for Universal Mobile Telecommunications System (UMTS). Mobile phone of radiofrequency (RF) radiation raises concern about possible implications to human health. As on 2106, an estimated 62.9% of the population worldwide already owned a mobile phone and the number of mobile phone users in the world is expected to cross the five billion mark by 2019. Today almost the entire world's population rely extensively on mobile phones for daily communication. With increasing dependency on mobile phones the system for mobile communication has also continually evolved and improved over the years catering to the needs and demands of this present age. Starting from the first generation mobile systems where only voice transmission was possible, technology has moved on to the fourth generation in which not only voice but internet data can also be transmitted at such high speeds that previous generations can only dreamed of. Evolving still, it is expected that within the next few years the fifth generation mobile communication networks will emerge to meet the increasing demands for high data rates for delivering data to mobile communication users. Therefore increasing exposure to mobile phone and mobile base station radiations, together with exposure to other non-ionizing radiations (power lines, radar, Wi-Fi etc.) are growing concern of possible adverse health effects. With increase in cell phone communication, number of cell towers getting installed is also increasing day by day. A cell tower also known as Base Transceiver Station (BTS) is usually an elevated metal structure which contains the antenna, transmitters and receivers located at the top of the tower. The purpose of a cell tower is that a mobile phone should receive adequate signal for its proper operation. These towers are essential part of mobile communication network, necessary to establish connection between the mobile telephone and the rest of the network. Cell phone signal strength is measured in decibel-milliwatts (dBm), a unit of electrical power in decibels (dB), referenced to 1 milliwatt (mW). One milliwatt of power is equal to 0 dBm. Since cellular signal operates on less power than that (as low as 0.000000001 mW, sometimes less), dBm signal strength is measured in negative numbers. The closer it is to 0 dBm, the stronger the cell signal; so, -60 dBm is stronger than -90 dBm. The milliwatt scale is logarithmic, which means that a change in dBm yields an exponential change in mW. For example, -70 dBm (0.0000001 mW) is ten times more powerful than -80 dBm (0.00000001 mW), one hundred times more powerful than -90 dBm (0.000000001 mW), and one thousand times more powerful than -100 dBm (0.0000000001 mW).

mW). Signal strengths can range from approximately -30 dBm to -110 dBm. In general, anything better than -85 decibels is considered a usable signal. A mobile phone shows full strength at -69 dBm input power and works satisfactorily in the received power range of -80 to -100 dBm. In comparison with -80 dBm level, the measured power level at 50m is at least 50 to 60 dB higher, which translates to 100,000 to 1,000,000 times stronger signal than a mobile phone requires. There are millions of people who are living within 50m distance from cellular towers and are constantly absorbing this radiation 24x7. For the signals to reach the mobile phones on every place, the towers have been located at every city corners and at every village of our country. In most Asian countries, towers have become ubiquitous, being erected every quarter of a mile radius, to ensure connectivity in large areas of the respective countries, e.g., India has total 17, 13,016 base transceiver stations (BTS -2G GSM and CDMA, 3G & 4G Mobile Towers) located at 4,61,407 sites all over the country [1]. Majority of these towers are mounted on or near the residential and office buildings to provide a good signal coverage to the users. A mobile phone tower and its transmitting power are designed in such a way that it provides coverage to at least a distance of a few kilometres, implying that a mobile phone at that distance should be able to transmit and receive sufficient signal for proper communication and intelligibility. Thus, a building situated at 10's of meter from the tower will receive about 10,000 times stronger signal than which is required for mobile communication.

All over the world, people and organizations have been debating about associated health risks due to radiation from cell phones and cell towers. There are numerous claims and counter claims regarding the ill effects and health hazards caused by radiations from mobile phones and mobile base stations. Radiation effects are divided into thermal and non-thermal effects. Thermal effects are those similar to that of cooking in the microwave oven. Non-thermal effects, however, are not well defined but it has been reported that the non-thermal effects are 3 to 4 times more harmful than thermal effects. When a human body is exposed to the electromagnetic radiation it absorbs these radiations because the human body is composed of 70% liquid. This is similar to that of cooking in the microwave oven where the water in the food content is heated first. Microwave absorption effect is much more significant by the body parts which contain more fluid (water, blood, etc.), like the brain which consists of about 90% water. And, the effect is even more pronounced at regions of the body where the movement of the fluid is less, for example, eyes, brain, joints, heart, abdomen, etc. Also, as the height of humans is much greater than the wavelength of the radiation emitted from cell towers, so there is also a possibility that multiple resonances may take place in the body which in turn may create localized heating inside the body. This effect results in the appearance of boils, drying up of the fluids around eyes, brain, joints, heart, abdomen, etc. causing irritation and various other symptomatic problems. There are several possible health hazards associated with cell phones and cell towers which include effect on skin, tinnitus and ear damage, sleep disorders, neurodegenerative diseases, cancer etc.

There are two parameters that need to be looked into to consider the effects of radiation from mobile phones and cell towers on animals, plants and humans in general. These are the Specific Absorption Rate (SAR) and the Power Density.

## II. SPECIFIC ABSORPTION RATE

The Specific Absorption Rate (SAR) is a measure of the amount of radio frequency energy absorbed by the body or more specifically, the mass of the biological tissue when using a mobile phone, and therefore is a very specific term related to the tissue in question because of the different conductivities exhibited by different tissues. It is basically defined as the radiofrequency power absorbed per unit mass of tissue and has units of watts per kilogram (W/kg). SAR is usually averaged either over the whole body, or over a small sample volume (typically a 1g or 10g area of tissue). SAR is measured using an internationally-harmonised standard. The SAR for electromagnetic energy is calculated by averaging (or integrating) over a specific volume of tissue by using the formula [2]:

$$SAR = \int_{sample} \frac{\sigma(r)|E(r)|^2}{\rho_m(r)} dr$$

Where,  $\sigma$  is the sample electrical conductivity,  $E$  is the RMS induced electric field from the radiated energy and  $\rho_m$  is the sample mass density.

The SAR value of mobile phones are usually tested by using a phantom head that is based on the dimensions of a large adult male head while ensuring worst-case measurements. The phantom head is filled with a liquid, contained in a manikin, that simulates electrical properties of human head tissue and SAR values are measured with the phone at maximum power and placed in a number of positions to simulate normal use. The measurement also includes tests with the mobile antenna in or out and at the various frequencies the model of phone is designed to operate. A probe inserted inside the liquid then measures the electric field strength inside the manikin and shows the maximum SAR value for the model of the selected mobile phone whose SAR value is being measured. Furthermore, the test method is so designed as to find the maximum SAR value for any mobile phone under test, which however, does not necessarily reflect the exposure limit in every-day use of the phone. In order to improve battery life and available call time, mobile phones are usually designed in such a way so as to constantly adapt to the minimum power required to make a quality call depending on reception and how close the user is to the nearest base station. This is called adaptive power control. It is a common misconception among the masses that using a cell phone with a lower reported SAR value necessarily decreases the user's exposure to RF emissions, or is somehow safer than using a cell phone with a high SAR value. While SAR values serve as an important tool in judging and knowing the maximum possible exposure to RF energy from a particular model of cell phone, however, a single SAR value does not necessarily provide sufficient information about the amount of RF exposure under typical usage conditions to reliably compare individual cell phone models. Rather, the SAR values collected by the various agencies such as the FCC, ICNIRP etc. are intended only to ensure that any particular cell phone does not exceed the maximum

limit of permissible exposure levels even when operating in conditions which may result in the device's highest possible RF energy absorption for a user. Maximum SAR levels for modern mobile devices are set by governmental regulating agencies in many countries. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published exposure guidelines in 1998 and recommended a localized SAR limit of 2.0 W/kg averaged over 10-gram of tissue for general public exposure, which is adopted by most European countries [3]. In the United States, the Federal Communication Commission (FCC) sets the localized SAR limit for public exposure to cell phone radiation to be 1.6 W/kg averaged over 1-gram of tissue. This means that for a wireless handset to receive ICNIRP certification and be sold in the European countries, its maximum SAR level must not exceed 2.0 watts per kilogram.

India has also adopted the ICNIRP regulations regarding the SAR values of mobile phones imported and manufactured in the country. In view of the heightened international concerns on the health consequences of wireless radiation the Indian government issued a new mobile radiation law that lowered the exposure limit of mobile handsets from a SAR of 2.0 W/kg to 1.6 W/kg averaged over 1-gram of tissue and made it mandatory for wireless device manufacturers to display the SAR values on their handsets. From the 1<sup>st</sup> of September, 2013 only those mobile phones which complied with the revised SAR value of 1.6 W/kg were permitted to be manufactured or imported in India.

### III. POWER DENSITY

Mobile communication antennas are usually designed to radiate in an omnidirectional (spherical) or a directional pattern. Theoretically, it is an isotropic, lossless radiator. An omnidirectional antenna radiates uniformly in all directions. Directional antennas radiate in a particular direction and are mostly employed in highly populated areas where communication sectors are targeting a specific set of people using mobile phones. In this kind of environmental setup the maximum radiation power density from an antenna is usually found at some distances away from the foot of the mast, due to the height of the antenna and its radiation beam pattern.

India has adopted the ICNIRP guideline and EU recommendation 1998 for the power density regarding maximum limit of exposure by the human body. The power density ( $P_d$ ) at a distance  $R$  is given by

$$P_d = \frac{P_t \times G_t}{4\pi R^2} \quad \text{watt/m}^2$$

Where,  $P_t$  = Transmitter power (in watt)

$G_t$  = Gain of the transmitting antenna

$R$  = Distance from the antenna (in metre)

According to the ICNIRP guideline the (maximum) power density for GSM 900 (935-960 MHz) is 4.5 watt/m<sup>2</sup> while for GSM 1800 (1810-1880 MHz) it is 9.0 watt/m<sup>2</sup>. However, the Department of Telecommunication (DoT), Govt. of India has revised the maximum limit of exposure with effect from 1<sup>st</sup> September, 2012 as 0.45 watt/m<sup>2</sup> for GSM 900 and 0.90 watt/m<sup>2</sup> for GSM 1800, and about 1.05 watt/m<sup>2</sup> for UMTS 2200 [4]. However, ICNIRP is only intended to protect the general public against short term gross heating effects and not against biological effects such as cancer and genetic damage from long term low level microwave exposure from mobile phones, BTS towers/antennas and many other wireless devices.

People can be exposed to harmful levels of RF radiation near the antennas of high power transmitters. Safety standards typically prescribed average power densities, averaged over 6 (six) minutes, to which people may be exposed. The public are generally ignorant about the level of RF power density around GSM base stations, the mechanism of interaction of RF radiation with biological units and the effect of RF radiation from mobile base station antennas on the human body. This has been a major concern to the public and it will take a lot of research and enlightenment to prove and create awareness respectively if there are any or no or limited health risks associated with these base stations. It is very important to assess the level of exposure to RF radiation from the numerous base stations antennas in our cities, town and villages to test their compliance with prescribed standards and to provide information on exposure scenarios to the public.

### IV. TYPES OF EMF RADIATION

Electromagnetic Field (EMF) radiations are broadly divided into two categories — ionizing and non-ionizing, depending on the frequency and the power level.

Ionizing radiation is the electromagnetic radiation whose waves contain energy sufficient to overcome the binding energy of electrons in atoms or molecules, thereby removing the electrons from the atoms or molecules on which they incident, thus creating ions and as well as being able to do lower-energy damage such as breaking chemical bonds in molecules. e.g., Ultraviolet rays, X-rays, gamma rays and cosmic rays as shown in fig.1 below.

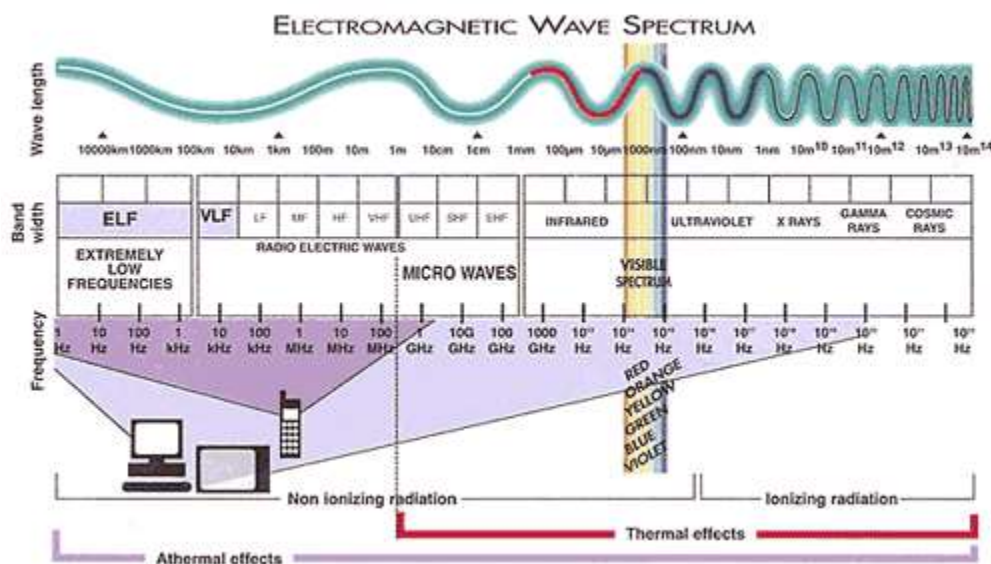


Fig. 1: Types of EMF Radiation

Electromagnetic Field emissions in the frequency range of 1 Hz to 1THz (1000 GHz) are termed as non-ionizing and these waves, in general, do not have enough energy to eject electrons and hence alter the chemical bonds of the human body. EMF health effects related to the non-ionizing radiation when exposure levels exceed the maximum limits include tissue heating. Electromagnetic Field emissions at frequencies above 1 THz are termed as ionizing and these waves have enough energy to eject electrons and hence to alter the chemical bonds of human tissues resulting in serious genetic damage when exposed over a long period of time. Ionizing radiation, which is caused by unstable atoms giving off energy to reach a more stable state, is more of a health threat to humans because it involves changing the basic makeup of atoms in cells, and more specifically the DNA molecules inside of cells. It does, of course, take a very strong dose of radiation to substantially damage a cell's structure, as there can be trillions of atoms in a single cell.

As some of the Electromagnetic Field radiations can ionize atoms/molecules and alter the chemical bonds of human tissues, they do have an adverse effects on the living organisms when exposed to these radiations for a prolong period of time. These radiations have the energy to break chemical bonds and cause serious damage to vital molecules of the body. If such a damage produced is minor, the cells may be able to heal up and eventually repair themselves, otherwise if the damage is major then cell death may occur, and dead cells cannot be replaced quickly enough.

There have been many studies suggesting either the presence or absence of risk to human beings from EMF radiation. The main areas of concern are the radiation emitted by the base transceiver stations (BTS) and mobile handsets. Concerns have also been raised that continuous exposure to EMF radiation emanating from telecom towers causes harmful thermal and non-thermal health effects. The effects of exposure to EMF have created an active scientific debate among the research agencies across the globe. In the recent past, people living in the vicinity of cell towers have raised the issue of adverse health effects of radiation emanating from cell towers. Numerous studies have been conducted in this regard in various countries and by various agencies and individuals alike. A group of experts believe that the EMF radiation emitted from BTS and mobile handsets causes health hazards to human beings, animals, birds, plants, etc. Some experts describe the short term health disorders caused by this kind of radiation as "microwave sickness" or "radiofrequency syndrome" which includes headache, fatigue, irritability, sleeping disorders etc.

## V. STUDIES OF EFFECTS OF EMF RADIATION FROM MOBILE PHONES & MOBILE TOWERS

### (i) Evidence of Effects on Brain:

In May 2011, Radiofrequency electromagnetic fields (RF-EMF) were classified as possible human carcinogens (group 2B) by the International Agency for Research on Cancer (IARC) [5]. This classification was made in the backdrop of various epidemiologic evidence, mechanistic support or animal modelling supporting a possible association between exposure to wireless phones and increased risk of glioma and acoustic neuroma [6]. Although various studies found that short-term cell phone exposure does not cause brain tumours, research is showing that it can change the brain's activity in ways that are not yet fully understood. Human brain cells communicate via electrical impulses, which can be detected by non-invasive EEG (Electroencephalogram) measurements. A study by Roggeveen S et al. found that during dialling of a mobile phone, when it is placed on the ear, its radiation (although not consciously sensed) is electrically detected by the brain. In the study, 31 healthy females were exposed to a 3G mobile phone for 15 minutes mobile and the exposure was compared to two 15 minutes sham phone conditions, one preceding and one following the exposure condition. Each participant was measured on two separate days, where mobile phone placement was varied between the ear and heart and EEG activity and radiofrequency radiation were recorded. Changed brain activity (i.e. cortical reactivity increase) was detected immediately after each radiation peaks, which are produced during the phone's normal dialling process [7].

The study by Roggeveen S et al. is not the first one to show an EEG change as a result of acute exposure to cell phone radiation. Many studies have investigated the effects of EMFs on resting cerebral activity with somewhat mixed results, but there

has been consistent data indicating the existence of exposure effects on the alpha bands of the resting EEG. Studies by Croft RJ et al. [8, 9], Hinrikus H et al. [10], Regel SJ et al. [11], Curcio G et al. [12] showed an increase in EEG power in the alpha frequency band, while other studies by Ghosn R et al. [13], Maby E et al. [14], Perentos N et al. [15], Vecchio F et al. [16, 17, 18] reported a decrease in EEG power or coherence in the alpha band. Still some other studies by D'Costa H et al. [19], Perentos N et al. [20], Hietanen M et al. [21] could not establish any effect on EEG power in the alpha bands. Most of the studies observed an effect, either increase or decrease, in the alpha band power. The reason for the fluctuations in the results i.e. observed increase in some studies while a decrease in some other studies is unclear but is attributed to the use of different methods, different experimental protocols, and/or different intensities or frequencies.

A study by Tombini M et al. demonstrated that an acute and relatively prolonged exposure to GSM-EMFs produced significant changes in brain activity (modulates cortical excitability) [22]; a study by Leung S et al. showed an effect of acute 2G and 3G exposure on human cognitive functions [23]; a study by Carrubba S et al. found that pulsed radiation from ordinary mobile phone use can trigger human brain evoked potentials (Eps) as detected by EEG. The study concludes that chronic production of the changes in brain activity might be pertinent to the reports of health hazards among mobile-phone users [24]. Using PET scans, a study by Volkow ND et al. demonstrated that 50 minutes of cell phone use changed human brain glucose metabolism in the region of brain closest to the phone antenna [25]. A study by Aalto S et al. also showed that mobile phone radiation induced changes in cerebral blood flow in humans [26]. The results obtained are consistent with the postulation that EMF radiation induces changes in neuronal activity.

As is evident from the above studies the human brain is sensitive to EMF radiation. The observed brain activity change cannot be explained simply on the basis of the heating (or thermal) effects as a result of temperature rise from energy absorption. However, as of the present dispensation, no underlying biological mechanism can be identified to explain the observed effects. Not much is also known as to the health consequences that may be resulted from such repeated stimulations. Therefore, more research is needed to completely understand the underlying mechanism and the long-term health effects of EMF radiation on the human brain.

Researchers have carried out several types of epidemiologic studies in humans to investigate the possibility of a relationship between cell phone use and the risk of malignant (cancerous) brain tumours, such as gliomas, as well as benign (non-cancerous) tumours, such as acoustic neuromas, also known as vestibular schwannomas (tumours in the cells of the nerve responsible for hearing), most meningiomas (tumours in the meninges: the membranes that cover and protect the brain and spinal cord), and parotid gland tumours (tumours in the salivary glands) [27].

The most important and comprehensive study for risk of glioma in relation to the use of mobile phones was obtained from the Hardell research group and the international cancer research department. It is widely accepted that the quality of work is higher and the result is worth referring to in the Hardell research group according to comparison with the Interphone group by Hardell et al [28]. No relationship was observed between risk of glioma and any period ipsilateral use of mobile phone as per the results of various meta-analyses [29–31]. However, long-term ipsilateral use was associated with increased risk of glioma. Contralateral use was not found to be associated with glioma regardless of the duration of mobile phone use. These findings suggest a possible role of long term exposure and specific localization of mobile phone as potential mechanisms linking mobile phone use with glioma [32, 33]. A meta-analysis of various low-biased case-control studies which was done by Myung SK et al. regarding the association between mobile phone use and tumour risk found that there is possible evidence linking mobile phone use to an increased risk of tumours [34]. The study suggested the need for other prospective cohort studies which would provide a higher level of evidence for the link. Another meta-analysis by Wang Y & Guo X also conclude that long-term mobile phone use may increase the glioma risk [35].

Results from various studies found evidence linking mobile phone use and risk of brain tumours especially in long-term users (>10 years). Use of mobile phones for  $\geq 10$  years give a consistent pattern of increased risk for acoustic neuroma and glioma, the risk being highest for ipsilateral exposure [35–38]. The review done by Khurana et al. investigated the relationship of brain tumour with wireless phone use for more than 10 years. This review which covered a total of about 11 meta-analyses showed that the brain tumours, which include glioma and acoustic neuroma increased 2-fold in those people who had been using wireless phones for more than 10 years, thus positively correlating by achieving a statistical significance [39]. The increased risk of brain tumours caused by prolonged exposure to mobile radiation was also confirmed by the CERENAT study [40], published in 2013, which supports the findings of the INTERPHONE and Hardell studies. The latest evaluation by Carlberg M & Hardell L regarding mobile use and glioma risk based on the Bradford Hill Viewpoints from 1965 on Association or Causation [41] also concluded that the radiation from mobile phones should be regarded as human carcinogen causing glioma [42].

A study by Moon IS et al. found that occurrences of Vestibular Schwannomas (VSs) coincide with that side of the ear where mobile phones are more frequently used and that the tumour volume showed strong correlation with frequency of mobile phone use, thus reflecting a possibility that mobile phone use may affect tumour growth [43]. Similarly, a study by Schoemaker MJ et al. suggests a risk of developing acoustic neuroma with long term use (> 10 years) of mobile phones [44]. Other studies by Victoria SB et al. [45], Lönn S et al. [46] and Benson VS et al. [47] also found an increased risk of developing acoustic neuroma with long term use of mobile phones.

Data from the largest-ever Animal Study of cell phone radiation effects, released by the federal National Toxicology Program (NTP), found an association between cell phone radiation and an increased risk for cancer. To simulate human exposure scenarios, the animals were exposed to RFR from the two technologies and frequencies widely used in the United States — Code Division Multiple Access (CDMA) and Global System for Mobile communications (GSM) — at frequencies of 900 and 1,900 megahertz. Importantly, the exposed rats were found to have higher rates of two types of cancers: glioma and malignant schwannoma of the heart, a very rare tumour. But, none of the unexposed control rats developed either type of tumour [48]. The incidence of those tumours increased as the rats were exposed to higher doses of radiation, suggesting that the radiation was responsible for the

appearance of the tumours. These findings, thus, reinforce the need for people, especially children and young people, to exercise caution when using cell-phones and other radiation-emitting devices.

**(ii) Evidence of Effects on Heart:**

A study by Roggeveen S et al. shows a significant drop in heart rate due to the placement of a dialling mobile phone on the chest [49]. Again, a study by Hussain D et al. showed that the rhythm of the heart changes continuously during the exposure [50]. A study by Vegad AM et al. demonstrate that the calls made with a mobile phone may influence Heart Rate Variability (HRV) and change the autonomic balance. It was found that, particularly in female subjects, the sympathetic tone increases accompanied by a corresponding decrease in the parasympathetic tone during the mobile phone calls which may have a deleterious effect on HRV [51].

A study by Yılmaz D et al. used non-linear analysis methods to determine the effects of electromagnetic fields (EMFs) emitted by GSM-900 based mobile phones (MPs) on the heart rate variability (HRV). Here they have used the largest Lyapunov exponent (LLE) calculation to evaluate the effect of MP under various real exposure conditions. Sixteen healthy young volunteers were exposed to EMFs emitted by GSM-900 based MP at two levels from a very low EMF (MP at stand-by) to a higher EMF (MP at pre-ring handshaking and ringing). A blind experimental protocol was designed and utilized by taking into consideration the physiological and psychological factors that may affect HRV. The results showed that the LLE values increased slightly with higher EMF produced by MP. This change indicates that the degree of chaos in the HRV signals increased at higher EMF compared to low level EMF. Consequently, the conclusion drawn was that high level EMF changed the complexity of cardiac system behaviour, significantly [52].

Similar studies by Ekici B et al. [53], Andrzejak R et al. [54] and Havas M et al. [55] show that there is a change in the HRV especially with long term exposure to waves emanating from mobile phones thus evidencing the fact that exposure to waves radiated by mobile phones or mobile towers can have a possible adverse impact on the human heart.

A study by Türedi S et al. [56] to investigate the effects of prenatal exposure to a 900 megahertz (MHz) EMF on rat pup heart tissue suggest that exposure to EMF in the prenatal period causes oxidative stress and histopathological changes in male rat pup heart tissue. The NTP study on rats was reinforced by the Ramazzini Institute (RI) study in which a statistically significant increase in the incidence of heart Schwannomas was observed in treated male rats at the highest dose (50 V/m). The RI performed a life-span carcinogenic study on Sprague-Dawley rats to evaluate the cancer causing effects of radio frequency radiation (RFR) in the situation of far field, thus reproducing the environmental exposure to RFR generated by the antennas of the mobile phone base stations. This is also the largest long-term study ever performed in rats (about 2448 animals) to indirectly estimate the health effects of RFR. The RI findings on far field exposure to RFR are consistent with the results of the NTP study on near field exposure, as both studies reported an increase in the incidence of tumours of the brain and heart in RFR-exposed Sprague-Dawley rats [57]. The significance of the RI study is that all RFR exposures were conducted at non-thermal levels that are considered safe and allowable for cell tower installations; yet a statistically significant increase in malignancies was found, therefore establishing that such very low levels of RFR can be harmful to humans and cause adverse health effects.

**(iii) Evidence of Effects on DNA and Cells:**

In a study by Sun Y et al., HL-60 cells derived from human promyelocytic leukemia were exposed to 900MHz radiofrequency fields (RF) continuous wave at  $120\mu\text{W}/\text{cm}^2$  power intensity for 4h/day for 5 consecutive days to examine whether such exposure is capable damaging the mitochondrial DNA (mtDNA) mediated through the production of reactive oxygen species (ROS). In addition, the effect of RF exposure was examined on 8-hydroxy-2'-deoxyguanosine (8-OHdG) which is a biomarker for oxidative damage and on the mitochondrial synthesis of adenosine triphosphate (ATP) which is the energy required for cellular functions. The results indicated a significant increase in ROS and significant decrease in mitochondrial transcription factor in RF-exposed cells compared with those in sham-exposed control cells. In addition, there was a significant increase in 8-OHdG and a significant decrease in ATP in RF-exposed cells. The results indicated that RF exposure was capable of inducing mtDNA damage through the production of ROS which also induced oxidative damage [58].

A similar study by Xu S et al. shows that 1800 MHz RF radiation could cause oxidative damage to mtDNA in primary cultured neurons which may account for the neurotoxicity of RF radiation in the brain [59]. In both of these studies, however, it is seen that these mtDNA disturbances could be reversed by pre-treatment with melatonin, which is a known effective antioxidant in the brain.

A study by Belyaev IY et al. on the effects of mobile phone microwaves (MWs) of GSM and UMTS on human lymphocytes from persons reporting hypersensitivity to electromagnetic fields and healthy persons reported that MWs affect chromatin and inhibit formation of DNA double-strand breaks co-localizing 53BP1/gamma-H2AX DNA repair foci in human lymphocytes from hypersensitive and healthy persons. The study data also validated the hypothesis that the type of signal (frequency) may have higher biological efficiency and possibly larger health risk effects [60]. Thus, UMTS MWs pose a larger health risk than GSM MWs. A similar study by Marková E et al. on the effects of MWs of Global System for Mobile Communication (GSM) at different carrier frequencies on human lymphocytes from healthy persons and from persons reporting hypersensitivity to electromagnetic fields (EMFs) found that MWs from GSM mobile telephones affect chromatin conformation and 53BP1/gamma-H2AX foci similar to heat shock and that effects of MWs from mobile telephones on human lymphocytes are dependent on carrier frequency [61]. Again, another study by Marková E et al. found that microwaves from mobile phones inhibited formation of tumour suppressor TP53 binding protein 1 (53BP1) foci in human primary fibroblasts and mesenchymal stem cells. The study also found that the strongest microwave effects were always observed in stem cells and that stem cells are most sensitive to microwave exposure and react to more frequencies than do differentiated cells [62].

A study by Eghlidospour M et al. to evaluate the effects of radiofrequency radiation emitted from a GSM 900-MHz mobile phone with different exposure duration on proliferation, differentiation and apoptosis of adult murine neural stem cells (NSCs) in vitro found that accumulating dose of GSM 900-MHz RF-EMF might induce devastating effects on NSCs proliferation and

neurogenesis [63]. Similarly, an in vitro study by Shahbazi-Gahrouei D et al. to investigate the effects of GSM 900 MHz on growth and proliferation of mesenchymal stem cells derived from adipose tissue (adipose tissue represents an abundant and accessible source of adult stem cells) showed that exposure to 900 MHz RF signal radiation from antenna can reduce cell viability and proliferation rates of human adipose stem cells [64].

A study by Chen C et al. to determine the effects of an in vitro exposure to 1800 MHz electromagnetic GSM field on the differentiation of mouse embryonic neural stem cells found that 1800 MHz RF-EMF exposure impairs neurite outgrowth of embryonic neural stem cells. Additionally, the study revealed that the mRNA and protein expression of the proneural genes which are crucial for neurite outgrowth were decreased whereas the expression of their inhibitor were increased after the RF-EMF exposure [65]. In another study by Y. Zhu et al. to investigate the effects of microwave emitted by mobile phones on the rat central nervous system (CNS), in vitro cultured cortical neuronal cells and in vivo rat's brain were exposed to the electromagnetic waves emitted by a microwave transmitter that mimics the working frequency of mobile phones. The study found that microwave emitted from mobile phones is harmful to both in vitro cultured cortical cells and in vivo brain neuronal cells from rat with cranial defect [66]. A study by Motawi TK et al. to investigate the effects of exposure to mobile phone radiations on oxidative stress and apoptosis in brain of rats found that the relative brain weight of young rats was greatly affected, and histopathological examination reinforced the neuronal damage [67]. In a study to investigate the cytogenotoxic effects of 900 MHz radiofrequency electromagnetic fields (RF-EMF) and the effect of a recovery period after exposure to RF-EMF on bone marrow cells of immature and mature rats by Şekeroğlu ZA et al. found that the exposure to 900 MHz and 1800 MHz RF-EMF leads to cytotoxic and genotoxic damage in immature and mature rats. The cytogenotoxic damage in immature rats was statistically higher than the mature rats. The recovery period did not reduce the damage to the same extent as the corresponding control groups [68, 69].

Another study by Çam ST & Seyhan N to analyze the short term effects of radiofrequency radiation (RFR) exposure on DNA of human hair root cells found that short-term exposure (15 and 30 min) to RFR (900-MHz) from a mobile phone caused a significant increase in DNA single-strand breaks in human hair root cells located around the ear which is used during the phone calls [63].

Studies by Lai & Singh on the effects of exposure to pulsed and continuous wave (CW) 2450 MHz microwaves in rats showed an increase single- and double-strand DNA breaks in individual brain cells of these rats after an exposure of about 2 hour [64, 65]. Again, a study by Hou Q et al. to investigate the potential adverse effects of mobile phone radiation found that an 1800-MHz EMR enhances ROS formation and promotes apoptosis in mouse embryonic fibroblasts (NIH/3T3 cells) after intermittent exposure (5 min on/10 min off, for various durations from 0.5 to 8 h) to an 1800-MHz GSM-talk mode electromagnetic radiation (EMR) at an average specific absorption rate of 2 W/kg [66].

A study by Guler G et al. investigated the oxidative DNA damage and lipid peroxidation levels in the brain tissue of pregnant and non-pregnant New Zealand white rabbits and their new born exposed to RFR. Thirteen-month-old rabbits (in four groups) were exposed to RFR 1800 MHz GSM for 15 min/day during 7 days. The results showed that 1800 MHz GSM radiofrequency exposure of non-pregnant and pregnant rabbits for seven days resulted in the release of secondary messengers, such as free radicals, leading to oxidative destruction in lipids and DNA. Also, rabbits which are prenatally exposed to cell phone radiation developed more indicators of DNA damage such as greater amounts of free radicals [67, 68]. A similar study by Tomruk A et al. to evaluate the possible biological effects of whole-body 1800 MHz GSM-like radiofrequency (RF) radiation exposure on liver oxidative DNA damage, lipid peroxidation levels and blood chemistry in non-pregnant, pregnant New Zealand white rabbits, and in their new born showed that RF radiation exposure may lead to oxidative damage as being indicators of subsequent reactions that occur to form oxygen toxicity in tissues [69, 70]. Again, a study by Ozgur E et al. to investigate the potential hazardous effects of prenatal and/or postnatal exposure to 1800 MHz GSM-like radiofrequency radiation (RFR) on the blood chemistry and lipid peroxidation levels of infant rabbits showed that different parameters of the blood biochemistry were affected by exposure in male and female infant rabbits [71].

Damage to cellular DNA is involved in mutagenesis and the development of cancer. Changes to the cellular genome can generate errors in the transcription of DNA and ensuing translation into proteins necessary for signalling and cellular function. Genomic mutations can also be carried over into daughter generations of cells if the mutation is not repaired prior to mitosis. Long term effects arise from irreversible mutations, causing loss or alteration of gene function. The outcome of DNA damage may be biased towards mutagenesis, which in turn triggers carcinogenesis. Alternatively, DNA damage, such as double strand breaks and interstrand crosslinks, may cause cytotoxic and cytostatic effects, which appears to be intimately linked with ageing.

#### ***(iv) Evidence of Effects on Male Reproductive System:***

An observational study by Agarwal A et al. involving 361 men who had attended an infertility clinic suggested that the use of cell phones adversely affects semen quality by decreasing sperm count, motility, viability and normal morphology which might have an adverse effect on male fertility. The study also found that the decrease in sperm parameters was dependent on the duration of daily exposure to cell phones and independent of the initial semen quality [72]. Another prospective cohort study by Zhang G et al. involving about 794 college students in the age group 20-22 years was carried out in China to investigate the effects of mobile phone use on sperm quality among students. Semen quality was assessed for each participant in 2013, 2014 and 2015 using four parameters (volume, concentration, total count, and motility) according to the criteria of the World Health Organization [73]. The study found that the use of mobile phones negatively affects sperm quality in men by decreasing the semen volume, sperm concentration or sperm count [74]. A similar retrospective study by Fejes I et al. involving 371 men of reproductive age but having infertility problems found that the duration of possession and the daily transmission time correlated negatively with the proportion of rapid progressive motile sperm, thus suggesting an adverse impact of prolonged use of mobile phones on sperm motility [75]. Again, in another retrospective study by Wdowiak A et al. involving 304 men it was found that the duration of mobile phone exposure increases the number of sperm cells of abnormal morphology and that a decrease in the

percentage of rapid progressive motile sperm cells in the semen is correlated with the frequency of mobile phone use [76]. Also, Davoudi M et al. observed declining levels of rapid progressive spermatozoa among a small study group of cell phone users [77].

The effects of mobile phone radiation on human sperm has also been corroborated by various in vitro studies and animal studies. A Prospective in vitro study of 32 men conducted by Agarwal A et al. showed that exposure of semen to radiofrequency electromagnetic wave(RF-EMW)leads to a significant decrease in sperm motility and viability, increase in reactive oxygen species level, and decrease in ROS–Total Antioxidant Capacity score. The study concluded that RF-EMW emitted from cell phones may increase oxidative stress in human spermatozoa leading to decreased motility and viability characteristics [78]. Again, in another in vitro study by Gorpichenko I et al. to examine the influence of mobile phone radiation on sperm DNA fragmentation and motility parameters in healthy subjects with normozoospermia, 32 healthy men with normal semen parameters were selected. The study found that an acute in vitro exposure of human sperms to a 900/1800 MHz GSM electromagnetic field influences DNA fragmentation and leads to a reduction in motile progressive sperms while there is a corresponding increase in the number of non-progressive motile sperms in exposed samples compared to control samples [79]. Also, in vitro studies by Eroglu O et al. [80] and Zalata A et al. [81] found a decrease in the sperm parameters of exposed semen samples. Another study by Rago Ret al. involving 63 healthy and fertile men found that mobile phone use of more than 4 h/day especially if the device is carried in the trouser pockets might result in DNA damage in sperms [82]. And, the results of a study by Falzone N et al. suggested a significant effect of radio frequency electromagnetic field radiation on sperm fertilization potential [83]. In another in vitro study by De Iulius GN et al. purified human spermatozoa were exposed to radio-frequency electromagnetic radiation of frequency 1800 MHz and specific absorption rates (SAR) ranging of from 0.4 W/kg to 27.5 W/kg. It was found that with increasing SAR, motility and vitality were significantly reduced after exposure, while the generation of reactive oxygen species and DNA fragmentation were significantly increased. Furthermore, it was also observed that there is a highly significant relationship between SAR, the oxidative DNA damage bio-marker (8-OH-dG) and DNA fragmentation after the exposure to the radiation [84].

In an experimental study conducted by Ghanbari M et al. on 28 adult male Wistar rats (200-250 g), the results obtained indicated that sperm viability, motility, and total antioxidant capacity in all the exposed groups decreased significantly compared to the control group. Also, when the duration of exposure is increased from 2 to 3 weeks it was found that there was a statistically significant decrease in sperm viability and motility [85]. Again, Yan JG et al. found that rats exposed to 6 hours of daily cellular phone emissions for 18 weeks exhibited a significantly higher incidence of sperm cell death than control group rats. Additionally, it was found that there were abnormal clumping of sperm cells in rats exposed to cellular phone emissions that were not present in the control group rats [86]. In another study by Kesari KK et al. to investigate the effect of free radical formation due to mobile phone exposure and effect on fertility pattern in 70-day-old male wistar rats found that exposure to mobile phone radiation leads to a significant increase in the generation of free radicals which might affect the fertilizing potential of spermatozoa and thus lead to infertility [87]. Other similar studies by the same authors were also able to reproduce the same studied effects on fertility [88, 89, 90, 91]. Again, a study by Mailankot M et al. on the effects of mobile phone radiation exposure on male albino wistar rats, it was found that continuous exposure of 1 hour for 28 days to 900/1800 MHz radiation results in a significant decrease in the percentage of motile sperms. Moreover, the exposure to radiofrequency radiation resulted in a significant increase in lipid peroxidation and decrease glutathione content in the testis and epididymis of the exposed group [92].

Many reviews and meta-analysis of various studies undertaken on the effects of mobile phone use and mobile radiation on sperm quality and other semen parameters have also highlighted on the negative and adverse impacts of mobile phone radiation on the human spermatozoa and male fertility, in general [93, 94, 95, 96, 97, 98, 99].

Apart from effects on sperm parameters there are also a number of studies which show effects of cell phone radiation on the testes. In a study by Salama N et al. on 24 adult male rabbits, they found that when the rabbits were exposed to mobile phone radiation (standby mode) opposite to that of the testes for 8 h daily for 12 weeks there is a significant decrease in the diameter of seminiferous tubules of the exposed group thus reflecting a possible effects on testicular function and structure in the adult rabbits [100]. In another similar study by Dasdag S et al. on 18 male wistar albino rats it was found that after exposure to mobile radiation the seminiferous tubules of the exposed group decreased as compared to the unexposed group [101]. In another study by Odacı E and Özyılmaz C twenty-four adult male rats were studied and divided into three groups: control, sham and EMF groups. The EMF group rats were exposed to 900 MHz EMF (1 h/30 day). After the study period, it was found that the diameter and epithelial thickness of the seminiferous tubules were significantly decreased in the exposed group compared to the other two groups. Additionally, it was observed that the EMF group rats exhibited vacuoles in seminiferous tubules basal membrane and edema in the inter-tubular space [102]. Again, a study by Karaman MI et al. on 21 adult male rats showed significant histopathological changes of the exposed group compared to the control group, including a large number of immature cells in the lumen of the seminiferous tubules, irregular canaliculi with less spermatogenic cells and canaliculi without lumen, thus showing an adverse hispathological effects on the testis with exposure to cell phone radiation [103]. Hanci H et al. studied the effects of a prenatal exposure to a radiofrequency electromagnetic field on the testes of 21-day-old rats and found that the diameter and epithelial thickness of the seminiferous tubules were significantly smaller in the exposed group. In addition, there were observed detachments of the basement membrane and immature germ cells were also found in the lumen thus suggesting that prenatal exposure to radio frequency electromagnetic wave could have a deleterious effect on the testes of the 21-day-old rats [104]. Kumar S et al. investigated the effect of 10 GHz exposure on the male wistar rat's reproductive system and found that the seminiferous tubules of the exposed group showed a significantly reduced diameter compared to those of the sham exposed groups and that testosterone level was significantly decreased with the shrinkage of testicular size [105]. Whereas, a study by Tas M et al. although it found no effect on the seminiferous tubules but it was found that the thickness of the tunica albuginea and the Johnsen testicular biopsy score were significantly reduced in the exposure group compared to sham exposure



group thus showing that exposure to radio frequency radiation may result in alteration of some or other reproductive parameters [106].

Studies have also shown the effects of mobile phone radiation on Leydig cells, also known as interstitial cells of Leydig, found adjacent to the seminiferous tubules in the testicle. These cells are responsible for producing testosterone in the presence of luteinizing hormone (LH) which in turn is essential for initiation and maintenance of spermatogenesis. In a study by Wang SM et al. to explore the effect of electromagnetic pulse (EMP) irradiation on structure and function of Leydig cells in mice it was found that EMP irradiation may cause significant injury in structure and function of Leydig cells in mice which in turn may affect spermatogenesis [107]. The study also discovered a decrease in the serum testosterone in the exposed group compared to that of the control group. In another study by Lin YY et al. to explore the effects of 1950 MHz RF electromagnetic radiation (EMR) on mouse Leydig (TM3) cells, the TM3 cells were irradiated or sham-irradiated continuously for 24 h by the radiation (SAR 3 W/kg). The results thus obtained indicated that the exposure to RF-EMR could have some adverse effects on TM3 cell proliferation and testosterone secretion and consequently have a bearing on spermatogenesis [108].

Given the results of the various studies on humans and animals and the fact that men who carry cell phones usually carry these devices in their trouser pockets or clipped to their belts at the waist while in talk mode, they may be exposing their testicles to harmful doses of radio frequency radiation which may have a direct bearing on their reproductive parameters and their fertility.

**(v) Evidence of Effects on Female Reproductive System:**

Although there are considerable evidences from numerous studies that cell phone radiation damages sperm and is associated with male infertility, little attention has been paid to studying the effects of cell phone radiation on female infertility and there have been only a limited number of studies to determine the effects of mobile phone radiation on female reproductive system.

In a study by Shahin S et al. to investigate the long-term effects of mobile phone (1800MHz) radiation in stand-by, dialing and receiving modes on the female reproductive function and stress responses (oxidative and nitrosative stress) female mice were exposed to mobile phone radiation in different operative modes. The study results showed that mobile phone radiation induces significant elevation in reactive oxygen species, lipid peroxidation, total carbonyl content and serum corticosterone coupled with significant decrease in antioxidant enzymes in hypothalamus, ovary and uterus of the exposed mice. Moreover, it was found that the exposed mice exhibited reduced number of developing and mature follicles as well as corpus lutea compared to the control group, thus suggesting that long term mobile phone exposure impairs female reproductive system possibly via inducing oxidative and nitrosative stress [109]. A review paper by Nazıroğlu M et al. examined previous research on chronic EMF exposure-induced infertility in females and males and correlated them with findings on EMF induced oxidative stress. The study found a link between EMF exposures and oxidative stress and overproduction of free oxygen radicals in female and male infertility [110]. A review study by Wojsiat J et al. which examined the role of oxidative stress in female infertility and in vitro fertilization found that oxidative stress may damage the oocytes (cells in the ovaries) and may impair their fertilization capacity, can also lead to embryo fragmentation and formation of numerous developmental abnormalities, and is regarded to be one of the important reasons of spontaneous and recurrent miscarriage. Moreover, overproduction of reactive oxygen species has a significant impact on the success of in vitro fertilization (IVF) [111]. Other similar reviews by Agarwal A et al. have also pointed the role of oxidative stress and free radicals in affecting female (and male) fertility [112, 113, 114, 115, 116].

In another study by Shahin S et al. to determine the effect of 2.45 GHz low-level microwave (MW) irradiation on implantation or pregnancy in female mice, twelve-week-old mice were exposed to MW radiation for 2 h/day for a total of 45 days. The results obtained showed that implantation sites were affected significantly in MW-irradiated mice as compared to control, together with a significant increase in reactive oxygen species (ROS), hemoglobin, RBC and WBC counts, neutrophil/lymphocyte ratio, DNA damage in brain cells, plasma estradiol concentration, and a significant decrease was observed in nitric oxide level and antioxidant enzyme activities of MW-exposed mice thus suggesting that MW radiation induced oxidative stress by increasing ROS production in the body which not only suppresses implantation, but may also lead to deformity of the embryo in case the pregnancy continues [117]. In a study by Yüksel M et al. to investigate the effects of mobile phone (900 and 1800 MHz) and Wi-Fi (2450 MHz) induced electromagnetic radiation (EMR) exposure on uterine oxidative stress and plasma hormone levels in pregnant rats and their offspring it was found that EMR-induced oxidative stress in the uteri of maternal rats increased during the development of offspring and may also lead to increased oxidative uterine injury in growing rats and decreased hormone levels in maternal rats [118].

Oxidative Stress is a very strong inducer of tissue damage and therefore the various studies indicated that cell phone radiation may cause significant damage to the tissues of the female reproductive system.

In a study by Chen H et al. they investigated the effects of 935-MHz electromagnetic radiation (ER) on fertilization and subsequent embryonic development in mice. Ovulating mice were irradiated at three ER intensities and it was found that Mid- and high-intensity ER at 935 MHz can reduce the fertilization rate and also the blastulation rate in mice, thus reducing the possibility of embryo implantation [119]. In a study by Gul A et al. to investigate any toxic effects of microwaves from cellular phones on rats' ovaries, 82 female pups of rats, aged 21 days (43 in the study group and 39 in the control group) were used after exposing pregnant rats in the study group to mobile phones that were placed beneath the cages during the whole period of pregnancy, the cages being made free from all kinds of materials which could affect electromagnetic fields. The battery of the mobile phone was charged continuously and the phone was switched on for 15 minutes in every 12 hours. The results of the study revealed that the number of ovarian follicles in the study group was lower than that in the control group thus suggesting that intrauterine exposure to mobile phone microwaves has toxic effects on ovaries [120]. A similar study by Türedi S et al. showed that prenatal exposure to continuous 900-Megahertz (MHz) EMF results in a decrease in ovarian follicle reservoirs in female rat pups at the beginning of the pre-pubertal period [121]. In another similar study by Roshangar L et al. to determine the effects of prenatal exposure of mice to low frequency electromagnetic field (LF-EMF) it was found that in the experimental group mice, compared to the control group, the primordial follicles were less developed and nuclei of oocytes with an electron microscope

appeared heterochromatic, shrunken and had vacuolated cytoplasm. The study concluded that exposure to EMF during embryonic developmental period can cause morphological changes in oocytes affecting both oocyte differentiation and folliculogenesis, thus resulting in decreased ovarian reserve and may lead to reduced fertility or infertility [122].

In other experimental studies on rats by Bakacak M et al. [123], Ahmadi SS et al. [124], Khaki AA [125] et al. and Roushangar L & Rad JS [126] to determine the effects of electromagnetic radiation on the ovarian follicles and oocytes differentiation, they found that exposure to electromagnetic radiation could seriously affect the number of follicles by reducing ovarian reserve and also affecting the oocyte differentiation thus leading to infertility or reduced fertility. Whereas, Diem et al. evaluated the effect of intermittent and continuous mobile phone radiofrequency electromagnetic fields (RF-EMF) exposure with different specific absorption rates (SAR) and different mobile-phone modulation on DNA strand breaks, *in vitro*, on cultured rat granulosa cells and found that RF-EMF exposure induced DNA single- and double-strand breaks after 16 h exposure (intermittent 5 min on/10 min off or continuous wave) [127].

In a prospective cohort study by Lynch CD et al. the researchers looked at women trying to get pregnant by measuring alpha-amylase (an enzyme with known association to stress) levels in their saliva as a predictor of whether they were successful. They found that women with the highest levels of this enzyme in their saliva had a 29% lower probability of pregnancy compared to those with the lowest levels [128]. Further, studies by Augner C et al. found that people living within a 100-meter radius of cell phone towers or mobile base stations had higher levels of biochemical stress markers, notably, salivary alpha-amylase. The study concluded that people living in the vicinity of cell phone base stations are more strained than others [129, 130]. Thus, the findings of these studies suggest that women who are trying to get pregnant and are exposed to electromagnetic fields from cell towers and cell phones are likely to have an increased level of salivary alpha-amylase i.e. are more stressed, and hence may have a 29% lesser chance of conceiving than those who are not exposed to these radiations.

Whilst there has been ample evidences from various researches linking mobile phone radiation and decreased sperm count and sperm motility, there are little or no strong evidences that link mobile radiation and female infertility. Many fertility experts believed that male fertility may be more susceptible to effects from mobile radiation than female fertility because the male testicles are not located as far inside the body as the female ovaries, and hence have lower protection and are more prone to exposure to the EMF radiation emitted by mobile phones. However, that aside, women should also have cause for concern because, whereas sperms are continually produced every 74 days throughout a male person's lifetime in their billions, all the eggs (oocytes) that a female person will ever have in her entire lifetime were in her ovaries even before she was born and cannot be added or replaced. In other words, her eggs unlike the sperms, are not expendable. It is therefore advisable that women who are pregnant or are trying to get pregnant should avoid or at least minimize the use of mobile phones to be safe.

#### **(vi) Evidence of Other Effects:**

Apart from the above effects there are also many other effects on the human health as studied by many scientists, scientific groups and individuals alike.

Oktay MF & Dasdag S [131] and Panda NK et al. [132] found that intensive and long term use of mobile phones have an effect on the ear causing inner damage and leading to loss of hearing. Whereas, Kerekhanjanarong V et al. [133], Velayutham P et al. [134] and Das S et al. [135] found that the effect on hearing is more on the dominant ear (the ear mainly used during calling) as compared to the non-dominant ear leading to a change in the hearing threshold of the dominant ear. And a study by Khullar S et al. concluded that long term exposure to mobile phone radiation may have an effect on conduction in the peripheral part of the auditory pathway [136].

Szykowska A et al. found a link between persisting headache and intensity of mobile phone use among mobile phone users [137], while Küçer N & Pamukçu T found that, among mobile phone users, significantly larger complains of headache came from women [138]. Also, Cho Y Met al. [139, 140] and Salama OE et al. [141] found a strong association between the duration of a phone call, the frequency of phone calls per day and the severity of a headache. A systematic review and meta-analysis of cross-sectional studies by Wang J et al. also found a significant association between mobile phone use and headache [142]. The study suggest further epidemiologic and experimental studies to affirm and understand the association between the two. Abdel-Rassoul G et al. [143] and Hutter HP et al. [144] found that people living in the vicinity of mobile base stations have significantly higher complains of headaches than those living far away and, Bortkiewicz A et al. in particular found that people living within a distance of 150 metres from the mobile base stations have a more frequent reported occurrences of headache [145].

A study by Huber R et al. demonstrated that the exposure to pulsed high frequency EMF during waking affects the brain function during the subsequent sleep period which is seen from the modification of sleep electroencephalogram (EEG) records during sleep [146]. A similar study by Borbély AA et al., Huber R et al. and Loughran SP et al. found that exposure to pulsed high frequency EMF affects human sleep and modifies sleep electroencephalogram (EEG) [147, 148, 149, 150]. Mann K & Röschke J. found that pulsed high frequency EMF induces a hypnotic effect with shortening of the sleep onset latency. Moreover, a suppression of the rapid-eye movement (REM) is observed together with a reduced period and reduced percentage of REM sleep [151]. Regel SJ et al. found a dose-response relationship between exposure to pulsed radio-frequency EMF and its effects on brain physiology as demonstrated by changes in the sleep EEG [152], and Schmid MR et al. again demonstrated that pulsed radio-frequency EMF affects brain physiology as is evident from the changes in the sleep EEG pattern [153]. A prospective cohort study by Thomée S of 4156 young adults in the age group 20-24 years found that exposure to mobile phone radiation causes sleep disturbances among high mobile phone users [154]. Again, cross-sectional studies conducted by Gómez-Perretta C et al. [155], Berg-Beckhoff G et al. [156] and Abdel-Rassoul G et al. [143] found that people living in the vicinity of mobile base stations are more affected by sleep disturbances than those who live farther away from the base stations thus indicating a possible role of mobile radio-frequency radiations in causing sleep disturbances. A report by the INDEPENDENT regarding a comprehensive study carried out by scientists from the blue-chip Karolinska Institute and Uppsala University in Sweden and from Wayne State University in Michigan, USA states that the use of mobile phones have been found to be linked

with delayed sleep and reduced sleep period. The research which was funded by the mobile phone companies themselves showed that people exposed to mobile radiation took longer to fall asleep and spent less time in deep sleep, thus adversely affecting components of sleep believed to be important for recovery from daily wear and tear [157].

In a study by Aldad TS et al. found that mice that were exposed in-utero to radiofrequency radiation from mobile phones are more hyperactive and also had impaired memory [158]. Whereas, in another study by Zhang Y et al. on in-utero exposure of mice to 9.417-GHz microwave radiation they found that pre-natal exposure to microwave radiation have greater effects on male offspring which is demonstrated by decreased learning ability and memory. However, no such effects were found in female offspring [159]. Nittby H et al. found that long term exposure to microwave radiation (GSM-900) significantly reduces memory functions in rats [160]. A study by Deshmukh PS et al. evaluated the effects 900 MHz microwave radiation exposure on cognitive function and oxidative stress in the blood of Fischer rats and found a significant impairment in cognitive function and increase in oxidative stress in the blood of the exposed rats [161]. Similar studies by Megha K et al. and Deshmukh PS et al. with 900, 1800 and 2450 MHz found a significant impairment in cognitive function and the induction of oxidative stress in brain tissues of microwave exposed rats compared with sham exposed groups [162, 163]. In other studies by Saikhedkar N et al. and Salford LG et al. extensive neuronal damage were observed in the brains of exposed rats which could cause alterations in behaviour related to memory and learning [164, 165].

As is seen from the above studies there are various other effects of electromagnetic radiation apart from the ones discussed. It is therefore important to take necessary precautions to avoid, especially, prolong exposure to mobile phone and mobile base stations radiations to minimize, if not completely eliminate, these effects.

## VI. AMBIGUITIES SURROUNDING STUDIES ON HEALTH EFFECTS OF MOBILE RADIATION

Although there has been numerous studies regarding the effects of EMF radiation, however, there have also been many counter studies that suggested no link between electromagnetic radiation from mobile phones or mobile base stations and health. The field of research as far as effects of mobile phone radiations are concerned is surrounded by controversy and further research is still needed to substantiate either claim.

Grafström G et al. studied the histopathological effects, such as neuronal damage, blood-brain barrier permeability and effects on ageing process and memory due to repeated prolong exposure to GSM-900 irradiation on rat brains and found that there are no significant histopathological effects when comparison is made between the exposed groups and the control groups [166]. Again, a study by Dogan M et al. to determine the effects of 3G mobile phone irradiation on rats' brain tissues found no harmful effects [167]. Also, a study by Kumlin T et al. to determine the possible morphological and functional changes in the central nervous system of young male wistar rats exposed to 900 MHz mobile phone signal found no serious threat from mobile phone radiation to the developing brain at intensities that are equivalent to human exposure [168].

In the CEFALO study which was a multi-centric case-control study conducted in Denmark, Sweden, Norway, and Switzerland to investigate the relationship between mobile phone use and risk of developing brain tumours in children and adolescents, the researchers did not find any causal association in the form of exposure-response relationship either in terms of the amount of mobile phone use or the location of the tumours [169]. Again the results of the Danish Nationwide cohort study did not find any evidence that linked mobile phone use and the occurrence of vestibular schwannoma [170]. In another update of the nationwide study of mobile phone subscribers in Denmark, the researchers found no indication of an increased risk of tumours of the central nervous system due to mobile phone use. Furthermore, in consonance with other studies there was no evidence of increased risk of meningioma nor that of glioma of the temporal lobes in long term subscribers although the temporal lobe has been described as the region of the brain where maximum absorption of energy emitted from mobile phones takes place [171]. Also, Christensen HC et al. in a prospective, population-based nationwide study, which included a large number of long-term users of cellular telephones, did not find any association between cell phone use and risk of acoustic neuroma [172].

In a study by Parazzini M et al. involving 26 young healthy volunteers who were exposed to 900 MHz (at SAR 2W) GSM cellular phone radiation they found no statistically significant evidence of effects both on main and other heart rate variability parameters [173]. Again, in another study by Parazzini M et al. to assess any change in the nonlinear dynamics of heart rate variability (HRV) during exposure to low-intensity EMFs it was found that the exposure did not cause any statistically significant effects on the nonlinear dynamics of HRV [174]. In a study by Barutcu I et al. to test the possible effects of short-term radiofrequency radiation exposure emitted by digital mobile phones on the cardiac autonomic modulation it was found that short-term exposure to electromagnetic fields emitted by a mobile phone did not affect the cardiac autonomic modulation in healthy subjects [175]. Similarly, Tamer A et al. did not find any effects on hemodynamic (heart rate, blood pressure) and cardiac electrical activity parameters when a mobile phone is positioned on the chest close to the heart, and neither any effect on cardiac autonomic function was found in healthy adult subjects as examined by analysis of heart rate variability [176]. Mann K et al. investigated the effects of weak high frequency electromagnetic fields emitted by digital mobile phones during human sleep on heart rate variability and found no such effects due to the electromagnetic fields on the autonomic control of heart rate [177]. Again, Barker AT et al. found that radiofrequency signals emitted from GSM mobile handsets had no effects on blood pressure or heart rate variability [178]. Also, the results of the study by Ahamed VI et al. found insignificant changes in the HRV indices when the position of the mobile phone is changed from holding close to the heart to holding close to the head [179].

In a study by Hook GJ et al. to determine DNA damage or apoptosis in Molt-4 T lymphoblastoid cells that were exposed to RF fields at different frequencies and different SAR values it was found that the exposure of Molt-4 cells to modulated RF radiation does not produce any statistically significant level of DNA damage or apoptosis between sham-treated cells and exposed cells [180]. In another study by Fairbairn DW & O'Neill KL it was found that exposure to electromagnetic fields have no significant effect in inducing DNA damage in human cells [181]. Again, a study by Danese E et al. found that exposure of human lymphocytes to 900 MHz radiofrequency radiation emitted by mobile phone does not have any significant effect on human DNA

[182]. Various *in vitro* studies have also found no effects on DNA due to exposure to radiofrequency or microwave frequency radiation. An experimental study by Vijayalaxmi et al. found no evidence of DNA single strand breaks in human blood lymphocytes which were exposed *in vitro* to pulsed-wave 2450 MHz radiofrequency radiation, either immediately or after 4 hours of exposure [183]. Again, other *in vitro* studies by Vijayalaxmi et al. found no evidence of induction of chromosomal aberrations and micronuclei in human blood lymphocytes exposed *in vitro* to cellular telephone frequencies (847.74 MHz, CDMA & 835.62 MHz, FDMA) [184, 185]. Similarly, a study by Stronati L et al. found no chromosomal and DNA damage in human lymphocytes exposed *in vitro* to a radiofrequency radiation (RFR) or a combination of x-rays and RFR. Furthermore, it was found that RFR have no influence on the genotoxicity of x-radiation [186]. Also, McNamee JP et al. found no evidence of genotoxicity induced in human blood cell cultures after a 24-h exposure period to continuous-wave (CW) and pulsed-wave (PW) 1.9 GHz RF-field [187]. Again, McNamee JP et al. found that acute exposure to non-thermal 1.9 GHz pulse-modulated RF-field do not cause DNA damage in cultured human leukocytes [188, 189]. Joubert V et al. found that exposure of human neuroblastoma cells to a 900 MHz global system for mobile communication (GSM) or continuous-wave (CW) radiofrequency fields for 24 h at SAR 2 W/kg for CW and 0.25 W/kg average for GSM does not cause any significant increase in the apoptosis rate in human neuroblastoma cell line [190]. Also, a study by Gläser K et al. did not find any effect of radiofrequency radiation on human hematopoietic stem cells exposed to mobile radiation at different SAR values ranging from 0 to 4 W/kg [191]. A study by Hirose H et al. found that low-level radiofrequency (RF) fields from mobile radio base stations does not induce p53-dependent apoptosis, DNA damage, or other stress response in human cells [192]. Also, Sakuma N et al. found that low-level radiofrequency (RF) fields from mobile radio base stations does not induce DNA strand breaks [193].

In a study by Dasdag S et al. on 31 wistar albino adult male rats it was found that mobile phone exposure of 2 h/day (7 days/week) to 900 MHz radiation over a period of 10 months does not have any apoptosis-inducing effect on spermatogonia in seminiferous tubules [194]. Again, a study by Ribeiro EP et al. found that exposure to low intensity radiofrequency radiation emitted from a cell phone does not have any significant effect on testicular function in adult male wistar rats [195]. Also, Dasdag S et al. found that exposure to radiofrequency radiation emitted from cellular phones does not have any adverse effect on either the structure or the function of the testes [196]. Lee HJ et al. found that sub-chronic exposure of male rats to 848.5 MHz (at SARs 2.0 W/kg & 4.0 W/kg) RF did not have any observable adverse effects on rat spermatogenesis [197, 198]. In another study by Lebovitz RM & Johnson L on Male Sprague-Dawley rats no statistically significant differences were found between the sham-irradiated and irradiated groups with respect to any measured variables such as net mass of the testes, epididymides, and seminal vesicles; daily sperm production (DSP) per testis and per gram of testis; sperm morphology and sperm count [199, 200]. An *in vitro* study by Falzone N et al. on human ejaculated semen found that exposure of highly motile human spermatozoa to mobile phone radiation at SARs 2.0 and 5.7 W/kg does not induce apoptosis related properties in human spermatozoa and hence does not lead to the impairment of fertility as reported in some studies [201]. Also, an *in vitro* study by Nakatani-Enomoto S et al. found no effects on sperm motility and oxidative stress due to exposure of human sperms to a 1950 MHz electromagnetic field [202]. In a cohort study conducted by Lewis RC et al. on 153 men in the USA to investigate the association between mobile phone use and semen parameters, no evidence was found for a relationship between mobile phone use and semen quality [203].

In a study by Yamashita H et al. to study and investigate the possible effects of short-term exposure to a 1439 MHz TDMA electromagnetic field on estrogenic activity in rats, Sixty-four ovariectomized female Sprague-Dawley rats were divided into four groups: EMF exposure (EM), sham exposure, cage control, and 17 beta-estradiol injected (E2). The study results found that although the uterine wet mass and serum estradiol level significantly increased in the E2 group, there were no differences among the other three groups indicating that the short-term exposure to a 1439 MHz electromagnetic field, as used in Japanese mobile phones, altered neither the serum estrogen concentration nor estrogenic activity in female ovariectomized rats [204]. In a study by Takahashi S et al. to evaluate the potential adverse effects of long-term whole-body exposure to EMFs simulating those from cellular base stations it was found that whole-body exposure to 2.14 GHz radiation for 20 hours per day during gestation and lactation did not cause any adverse effects on pregnancy or the development of rats [205]. Again, Shirai T et al. found no adverse effects on pregnancy or on the development of rats due to simultaneous whole-body exposure to eight different communication signal EMFs at frequencies between 800 MHz and 5.2 GHz [206]. A study by Suzuki S et al. to evaluate the effects of 3G cellular phone radiofrequency-electromagnetic wave (RF-EMW) exposure on fertilization and embryogenesis in mice found that exposure to a radiofrequency electromagnetic field had no influence on fertilization and embryogenesis of mice *in vitro*. Further, since the exposure level in the study was 100 times greater for sperm cells and oocytes than in daily exposure in real life, the study concluded that RF-EMW are safe for humans [207].

Apart from these, there are other studies as well which found no effects of mobile radiation on the other parameters such as ear, headache, sleep, cognition and memory etc. These studies, therefore, created some confusion and controversy regarding the health effects of mobile phone and mobile base station radiations.

## VII. DISCUSSION

While there have been numerous studies on the possible health effects of mobile phone and mobile tower radiation there are various other studies also which pointed otherwise. A hazy cloud of science and scepticism has hovered over the health concerns of cell phones for decades. There have also been studies which pointed out that the source of the funding could be a significant factor in the outcomes, results and most importantly the interpretation of results of such studies. In a systematic review by Huss A et al. on various studies of controlled exposure to radiofrequency radiation with health-related outcomes it was found that the source of funding have a significant impact on the interpretation of the results from studies of health effects of radiofrequency radiation [208]. Again, Levis AG et al. also found that funding sources play an important role on the outcomes of the studies regarding effects of mobile radiation [209]. A study published by Environmental Health Perspectives, the journal of the

National Institute for Environmental Health Sciences, also found that research funded by the cellular telephone industry tended to show less harmful effects than independent or government sponsored researches.

Reports such as the bioinitiative 2012 have reported clear links that established the bio-effects that occur even at very low levels of exposure to electromagnetic fields and radiofrequency radiation [210]. However, there are some other organisations or agencies which stated that the present studies could not establish concretely any such relations. The American Cancer Society (ACS) and the National Institute of Environmental Health Sciences (NIEHS) argue that the weight of the present studies lack scientific evidences that can conclusively link cell phone use and any adverse health effects, and that further research is still needed. Secondly, physicists have not known any plausible biological reason or reasons why radiofrequency radiation might damage human cells. It's not like radiation from X-rays or radioactive material which can damage cells' DNA. Another important point of contention is that most of the studies that has been done were on animals, and that these animals were subjected to very high levels of radiation to which humans are unlikely to be exposed in their daily use of mobile phones or from mobile towers or in their entire lifetime. These conflicting studies and arguments make it very difficult for the public to draw conclusions while the two sides battle it out. The lack of clear dose-response relationships make it very difficult to draw some positive conclusions regarding any causal relationship between cell phone use and human health effects, or the effects of mobile and mobile tower radiation on the environment as a whole. Still, as more people, in particular children and teenagers, spend more time with their cell phones, the murky margins of scientific evidence and lingering uncertainty are very likely to stir more concerns and debates.

## VIII. CONCLUSION AND SUGGESTIONS FOR FURTHER RESEARCH

In this paper we reviewed and summarized some of the important researches done to study the biological effects of cell phone radiation. Although, there are many evidences pointing towards the negative effects of the cell phone and mobile base stations radiation on human health but we are still in need of more research works to confirm the evidences we have. Long-term cohort studies and experimental follow-ups are much needed so as to clearly establish the health effects, if any, due to the use of mobile phones. Results from current studies such as the COSMOS study and the SCAMP study etc. will prove to be very effective in gaining important insights as to prevailing environment of confusion to the use of mobile phones and their health effects.

One of the most significant aspects with regards to the way in which evidence from scientific studies is interpreted and accorded credibility is the fact that the same can be verified, confirmed or, more aptly, replicated. The results of any individual study alone cannot be considered sufficient to establish or refute a possible human health risk. Individual studies must be validated and replicated before they can be relied on, and the determination of whether a potential health hazard exists requires a weight of evidence that evaluates all relevant, credible and valid data. In most, there is a lack of human volunteer studies that would, in unbiased ways, demonstrate whether human body responds at all to mobile phone radiation. Finally, the epidemiological evidence is insufficient due to, among others, selection and misclassification bias and the low sensitivity of this approach in detection of health risk within the studied population. This indicates that the presently available scientific evidence is insufficient to prove reliability of the current safety standards. The current safety standards might be the best that can be done using the presently available scientific evidence and they should not be altered arbitrarily, without scientific evidence and justification. However, these standards are not yet sufficiently supported by the science and cannot be considered as scientifically reliable. Therefore, we recommend to use precaution when dealing with mobile phones and, whenever possible and feasible, to limit body exposure to this radiation since in most of the studies it was found that the reported health effects are from long-term exposure to EMF radiation. Continuation of the research on mobile phone radiation effects is needed in order to improve the basis and the reliability of the safety standards.

It is worth a recommendation that further research should be conducted and studies should focus more on dose-response relationship and try to positively identify the various possible mechanisms by which EM field interacts with the human body and how the radiation exposure relates to health effects. A positive relationship will help regulating agencies to come up with much more stringent laws regarding permitted exposure levels and thus prevent any catastrophic health outbreak on an epidemic scale in the distant future, while a negative relationship will help allay fears and suspicions from the general populace which have become increasingly dependent on this and other related technologies.

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