

Thermal and Non-Thermal Effects of Mobile Phone Radiations on Humans

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Abstract—With the increase in the number of mobile phone users to 7.4 billion for the past decade, it is imperative to analyze the potential harmful effects that its increased use can cause on humans. Research has been carried out in this field for almost two decades both in favor and against the claim that the use of mobile phone has potential harmful effects. The effects can be classified as thermal and non-thermal based on their nature. In this paper, the effect of radiofrequency radiation on different functions of the body was reviewed including effects on EEG, Blood brain barrier, Cognitive function of children, Reproductive, Development of cancers and genotoxic effects. The most dangerous effects are implied by the studies aimed at analyzing the potential effect of radiofrequency radiation on development of brain tumors. Therefore, more studies must be conducted on human subjects rather than animals in order to investigate these effects and also validate the previously conducted studies.

Keywords— Cancer; Humans; Mobile phone; Radiation.

I. INTRODUCTION

Mobile phones are essentially transmitters which operate in the radiofrequency range of the Electromagnetic spectrum in the range of 450 to 2700 MHz. The power range of mobile phones ranges from 0.1 to 2 watts. They use radio wave transmissions using fixed antennas called base stations. Radiofrequency waves are non-ionizing in nature and do not cause ionization in the body. In the past few years, the possibility of adverse health effects caused by radiofrequency waves emitted by our mobile phones has been a subject of debate and increasing concern worldwide. As of 2016, the number of mobile phone subscriptions is 7.4 billion. Since many people are using the mobile phone, it is important to understand the potential public health impact that the mobile phone radiations can cause. Some of the radiofrequency waves from the mobile phone are emitted into the surroundings while some part of it is absorbed by the body, particularly the head and neck region. The rate at which the human body absorbs energy is measured in terms of the Specific Absorption Rate (SAR). The biological system is affected by electromagnetic radiation in two ways namely, the thermal effects which are caused by high intensity RF power and the non-thermal effects caused by the low power radiation. A lot of research has been carried out in order to investigate the thermal effects of radiation which is caused due to the localized heating of the tissue in the vicinity of the mobile phone. These effects include Cataract formation, disturbed sleep, increased heart rate, decreased cognitive function and high blood pressure. The potentially dangerous effect of radiofrequency exposure is based on establishing a link between brain tumors and mobile phone usage. On the basis of strong evidence collected from the Interphone Study, IARC (International Agency for Research on Cancer) in 2011 has categorized radiofrequency electromagnetic fields as

“possibly carcinogenic” to humans (Group 2B)[1]. Thus, it can be inferred that there could be some risk associated with the use of mobile phone, more evidence of which has to be collected in order to substantiate the claim. Therefore, it is important to investigate further on the connection between the use of mobile-phone and risk of brain-cancer. Also, a study of methods to reduce the exposure of humans to mobile phone radiation has to be conducted [2, 3].

II. EFFECTS OF MOBILE PHONE RADIATION (THERMAL AND NON - THERMAL)

A. Effect on EEG:

EEG or Electroencephalography is a diagnostic technique used to track the electrical activity of the brain in order to detect abnormal brain function. It is also used in experimentation for research to understand how the brain really functions. Recording the EEG is a non-invasive method and is performed with the help of electrodes. For diagnosis of disorders relating the brain, neural oscillations or brain waves, as they are called, are considered important[4]. Several laboratories around the world have suggested that the electrical activity of brain could be altered by the microwave radiation emitted by the mobile phones.

James C Lin in his paper published in 2003 has suggested that human EEG activity can be affected because of the radiation emitted by mobile phones[5]. In the same paper another study suggests that sleep may be promoted by the emission of pulse-modulated microwaves from mobile phones. Sleep is comprised of stages which are marked by brain waves that cycle throughout sleep. During sleep, Non-Rapid Eye Movement (NREM) also called slow wave sleep and Rapid Eye Movement (REM) are the two stages of EEG activity. The waveforms of an EEG are subdivided into bandwidths called

Delta (<4Hz), Theta (4Hz to 7Hz), Alpha (8Hz to 15 Hz) and Beta (16 Hz to 31 Hz). All-night polysomnographs (used to detect sleep disorders) were recorded, before and after exposure to the signals from GSM phones at 0.5 W/m². Healthy male subjects were used for this experiment. It was observed that diminishing sleep-onset latency was induced in the subjects. Also, the presence of a REM-suppressive effect which was characterized by decrease in the percentage and duration of REM sleep was detected. However, this study provided conflicting results since EEG patterns of 20-24 subjects during sleep at power densities ranging from 0.5 to 50 W/m² were not in line with the above-mentioned findings.

In another study by R. Huber et al, subjects were exposed to cell phone fields for 30 minutes during waking period just before sleep[6]. This study concluded that exposure during waking causes a modification in EEG during succeeding sleep. This study was further substantiated with evidence proving that exposure to radiofrequency waves emitted by mobile phones affects EEG patterns recorded during sleep. Latency in the onset of sleep was found under exposed condition (13 – 15 minutes). This effect is more evident under GSM modulated fields compared to CW modulated fields.

Analyzing the EEG in awake subjects has also been performed. A change in absorbed power of frequency band named delta of EEG recording from one of five telephones used for the experiment was observed. Since delta brain waves present in awake adults is indicative of neural pathology, therefore the authors drew the conclusion that “the observed difference in one parameter was probably caused by statistical chance.” In another study conducted by C.K. Smitha et al, Higuichi’s fractal dimension analysis was used as a tool to analyze the fractal dimension of EEG and the experiment was carried on 10 volunteers with and without exposure to Radiofrequency emissions from mobile phones [7]. The mobile phones used for this experiment had different SAR values. The analysis showed some changes in the FD (Fractal dimension) as a result of mobile phone use, which demonstrate change in brain activity due to exposure to radiation. This study, therefore concluded that radiations emitted by the cell phones could cause a modification in the electrical activity of the brain in sleeping and awake condition.

B. Effect on Blood Brain Barrier:

The blood–brain barrier (BBB) is a selectively permeable barrier which acts as a partition between the blood circulating in the brain and the brain extracellular fluid. It is comprised of endothelial cells which are tightly held together facilitating the selective permeability of the barrier. The blood brain barrier has very high electrical resistance and it protects the brain from compounds in the blood that can be potentially dangerous[8].

Initial studies about the effect of Mobile phone radiation on BBB were carried out in 1970 when the observation of increased leakage of fluorescein after being

exposed to pulsed and CW exposure for 30 minutes was made. Also leakage of insulin, dextran and C-mannitol at very low levels were observed[8].

A study carried out by James C Lin, showed a high SAR could lead to a change in the permeability of the Blood brain barrier[9]. Traces and markers used in the experiment were indicative of the fact that when the microwave power absorption is high (1.65 W/kg) which is enough to increase the temperature of rats to approximately 42 degree Celsius, the permeability of the BBB is increased for substances that are generally eliminated.

Recently conducted studies have indicated that the microwave exposure can modify the BBB permeability at SAR’s that are below the level of maximum permissibility for a mobile phone. This report by Salford et al suggested that serum albumin is leaked by the BBB upon exposure to microwaves from the cell phone [10, 11]. This study also reveals that both pulsed microwave and Continuous wave can make the BBB permeable to albumin which can lead to epilepsy. However, this analysis was subjective. In subsequent studies carried out after 7 weeks and with 2 hour exposure to 0.002 - 0.2 W/Kg, dark neurons were found in high concentration. However, the result of albumin detection was not perceptible.

Another study by Henritta Nittby et all on the basis of the repetition experiments of increased BBB permeability suggest that the Blood brain Barriers that are already damaged or disrupted will be more prone to Radiofrequency fields when compared to uninjured BBB[12]. Using fluorescein labeled protein, discharge of albumin was observed even at non-thermal SAR values of 0.12, 0.5 and 2 W/Kg. This study was further carried out in order to assess the neuronal damage that could have been caused by the increased penetration of albumin. The cresyl violet staining indicated that there was grouped and sometimes scattered presence of dark neurons with the brain parenchyma.

An increased permeability to rhodamine ferritin complex through BBB at 2 W/Kg exposure level and 30-720 minutes has also been observed. More recently, uptake of sucrose by the BBB on exposure to Electromagnetic radiation of 1.8 GHz has been studied but the results were found to be contradicting when the BBB model was modified to one with higher tightness.

Studies focusing on the non-thermal effect of mobile phone radiation have essentially found no evidence proving that there is any adverse effect of the same on human body. Both chronic exposure (1-4 weeks, 5-6 days per week, 1-1.5 hours per day) and acute exposure (10 minutes) were applied to study the effect. All these studies concluded that there is no effect of albumin permeability through BBB, neurodegenerative markers and number of dark neurons.

C. Mobile Phone radiation and cancer:

Possible adverse health effects like cancer caused by radiofrequency has been a subject for research around the world [13]. A feasibility study was carried out by the IARC in 1998 to 1999 which indicated that the study on the link between brain tumor and mobile phone is imperative and would be useful. A case-controlled study named Interphone aimed at ascertaining the relationship between the mobile phone radiation and risk of developing cancer was started in 13 different countries and results were published in 2010. This study focused on four types of tumors i.e. Meningiomas (Tumors of the brain caused in the meningeal tissue. It is generally benign in nature.), Gliomas (Tumors arising in the brain or the spine and are malignant in nature), parotid gland and acoustic nerve. The parameters that were taken into consideration in this study were with respect to years since first use, cumulative hours of use, the duration of use and cumulative number of calls. The IARC and WHO has categorized radiofrequency fields as “possibly carcinogenic to humans (Group 2B), based on an increased risk for glioma, a malignant type of brain cancer, associated with wireless phone use [1, 14-17].”

This category i.e. Group 2B is applicable in cases where evidence proving cancerous effects in humans and experimental animals is not enough. It can also be applicable in case of insufficient evidence in support of carcinogenicity in humans but there is adequate evidence of the same in experimental animals. Sometimes a case placed in this category is an agent having insufficient evidence of cancerous effect in humans and less than enough evidence in experimental animals integrated with evidence from pertinent and deterministic data.

In the study carried out by E. Cardis, any risk causing glioma or meningioma in relation to use of mobile phones was ruled out.[18] However, suggestions about increased risk of glioma or meningioma on exposure to high levels of radiofrequency radiation were made. Furthermore, this study accepted that errors and biases restraining strength of the inference cannot be ruled out and therefore prevent a causal explanation.

For long term usage, the interphone study report is inconsistent because the odds ratios for glioma and for meningioma are shown to be 0.81 and 0.79 respectively. This same study shows an odds ratio (OR) of 2.18, 1.82 and 1.49 for development of glioma in accordance with regular use of 10 or more years according to a study conducted by James C Lin[19, 20]. This investigation was carried out using a class of users whose mobile phone usage is minimal. Additionally, an overall decreasing trend in the risk of glioma with cell phone use has been reported by the interphone study. This downward trend is indicative of a weakness in the methodology which could be a result of unwillingness of larger number of subjects to participate in the study, selection or participation prejudice and authenticity of subjects to recapitulate overtime. Also, the

interphone study was initiated and completed within 10 years' time frame. Since brain tumors are known to have a dormancy of longer than 10 years and in some cases even 30 years. This limited the ability of the interphone study to detect cancers that could have possibly been caused due to cell phone radiations.

Furthermore, the 'heavy users' defined by the interphone study to be 40% more prone to cancer, fall in the range of users who use their cell phone for 30 minutes a day. On the contrary, in the present scenario where the number of mobile phone subscriptions has increased dramatically, 30 minutes of usage of mobile phone may no longer be considered heavy. Also, this study does not consider the effect of mobile phone use in children (which is increasing nowadays). The skulls of children are thinner compared to adults and are more susceptible to the radiation emitted by cell phones.

Study by Peter D. Inskip et al on the trends of brain cancer incidence relating cellular telephone use in the US did not provide any proof to the view that brain cancer is caused by use of cell phone[21]. Age and sex of patients were key factors in this study. According to the study conducted, for those in the age group of 35 to 60 years, the incidence of brain tumors increased from 1977 to 1991. Here, an exception of the age group of 20-29 years was observed where the trend was downward or flat for the years between 1992 and 2006. Among women aged 20-29, an increasing trend was reported. No such trend was observed in case of males. The increased rate from 1977 to 1991 was anticipated because these patterns had already been documented and this increase is attributed to the better healthcare facilities like better diagnosis, MRI's and CT's that were made available around that time. Moreover, cellular telephones were introduced in the US only after 1990, and the incidence rates of cancer have only been flat or decreased ever since. In this study the only group that showed an increasing trend was a group of 20-29-year-old females. An increasing trend would have been interpreted as proof to substantiate the claim that cell phone radiations cause cancer. But further examination of the study revealed that the patterns are inconsistent with causal interpretation. The part of the brain most susceptible to RF fields is the temporal lobe. But, no incidence of cancer was observed in the temporal lobe. Rather, increase in Frontal lobe Tumors caused the overall trend. In another study by the same author, the conclusion drawn is that with the large scale use of mobile phones, increase in the frequency of cell phone use in a day, and improvement in the technology with time, the observations should be viewed as an approximation of the risk at a premature stage of the use of mobile phones [13].

D. Effect On Cognitive Function Of Children:

Research has been carried out in order to investigate the effect of mobile phone radiation on children. However, not much literature is available on this subject and the research carried out does not provide sufficient evidence to draw a

conclusion. Studies have been carried out previously reporting changes in cognitive function of children but the limitation of these studies was that they were performed with less number of subjects which made it difficult to deduce the results clearly[22, 23].

A study which involved secondary school children from Australia was carried out to examine the effect of radiofrequency fields on cognitive functions of children. 317 students from 7th grade which included 173 girls and 144 boys with an average age of 13 years participated in this study[24]. Most of these 317 students had already used a cell phone and 243 owned their own cell phone. Cognitive function was determined with the help stroop color word test and computerized psychometric test battery Cog health. The cognitive function domains that were assessed by this experiment are listed as below:

- Signal Detection: When a stimulus is provided, the time taken by the subject to observe the stimulus, react to the stimulus in the form of a motor function and to differentiate between two different stimuli was assessed in this test
- Working Memory: The potential to be able to capture information and keep it stored in the short-term memory is studied in this test. This task is performed using two back tasks which involve keeping something in the memory, comparison with another item and an interceding item which is then removed. Accuracy and reaction time are primarily assessed in this task.
- Simple/ One card learning: This test is based on the ability of subject to visually recognize an item. The child is asked to answer in Yes/No based on his/her ability to recognize the item shown.
- Associative learning: The task is based on the learning capability of association between objects on playing cards.
- Movement monitoring: The task monitors the psychomotor operation of the subject. It assesses the ability to anticipate the motion of an object.
- Stroop color: The subject is required to read words standing for names of certain colors. The intervention task requires child to recognize the color in which the word is written and to read the word. This task is particularly performed where the color and the word are discordant.

Study reported that children who received more phone calls per week demonstrated shorter time of response for simple and associative learning tasks. On the contrary, more frequent users of the cell phone showed lesser exactness on working memory. In the word-color test, children who made/received more phone calls per week showed more interference of words printed in dissimilar colors.

The study also concluded that greater the number of Short Text Messages (SMS) sent and received by the children

corresponds to less accurate response to working memory and associative learning tasks. However, in terms of response time, a greater number of text messages resulted in shorter response time to learning tasks. No relationship was found between SMS and signal detection and movement tasks. Similarly, no link could be established between SMS and interference by words printed in different color.

Therefore, the use of cellphone both for calls and SMS leads to a decrease in the reaction time of both simple and associative learning tasks. However, the accuracy both for working memory and associative learning was poorer for increased cell phone use. These results are intriguing because the exposure to radiation reduces by half when a person is texting instead of making a call because of the proximity of mobile phone to the head.

So, in conclusion cell phone causes shorter but less accurate responses in cognitive function tasks. Except for the complex word naming tasks, the results suggested that cognitive changes are not essentially due to exposure to radiofrequency fields. Instead, the author concludes that this behavior may be caused due to increased use of cell phone and acquired cognitive skill. These results, however, have to be further investigated and subsequent experimentation has to be carried out with greater number of subjects participating in the study in other countries.

E. Effect on Reproductive system :

Research has been carried out in order to investigate the effect of mobile phone radiation on children. However, not much literature is available on this subject and the research carried out does not provide enough evidence to draw a conclusion. Studies have been

Most of the males of reproductive age possess mobile phones. Since the number of men owning the mobile phone is large, there is growing concern over the effects that the mobile phone radiation might have[25, 26]. This section primarily focuses on the effect of mobile phones on spermatogenesis which can adversely affect the sperm quality and eventually lead to infertility. A report suggests that 15% of the couples of reproductive ages are infertile. It is therefore imperative to assess whether mobile phone radiation has any relation to causing infertility in males.

A study performed by Ashok Aggarwal et al on 361 men with an age 31.81 ± 6.12 years. Patients with history of other conditions that could otherwise affect the sperm count were excluded from the study[27]. Eight parameters were analyzed for semen analysis which are sperm count, volume, liquefaction time, pH, viscosity, motility, viability, percentage of normal physiology. The subjects were divided into four groups. Group A which included subjects who did not use the mobile phone at all (40). Group B who used their mobile phones for 2 hours per day (107). Group C where the mobile phone usage was 2-4 hours per day (100) and group D in which subjects used their mobile phones for more than four

hours per day (114). Four of the sperm parameters: sperm count, viability, motility and normal morphology were found to be different among all groups. However, an adverse effect on the quality of semen is observed which could be the cause of infertility among these males. The four sperm parameters however showed a positive interconnection between each other which means a decrease in one corresponds to the decrease in another parameter. Another significant observation of this study is that the semen quality showed a dependency on the mobile phone usage time. The four sperm parameters show a decrease in the group that used the cellphone for longer duration i.e. more than 4 hours in the day.

Kavindra Kumar Kesari et al studied the effect of mobile phone radiation exposure on the reproductive pattern of male Wistar Rats (Male Rats)[28]. The rats were divided in two groups, one control (unexposed) containing six rats and another exposed group which also contained six rats. The exposed group were administered with a radiation dose with SAR value of 0.9W/Kg for a period of 35 days which accounted for the exposure time of 2hours per day. The total sperm count of exposed group had less normal cells in comparison to apoptotic cells. On the contrary, in the control group, number of normal cells was marginally greater compared to apoptotic cells. It can therefore be inferred that the mobile phone radiation exposure caused the cells to get damaged. This study also reported a decrease in the Glutathione peroxidase levels which is responsible for protecting the organism from oxidative damage. Similarly, super dioxide dismutase activity showed a significant decrease after exposure to radiation. This leads to a decrease in the antioxidant defense catalase activity. When the exposed males were allowed to mate with the exposed females, the progeny was lesser compared to control group and also a decreased body weigh was reported. Therefore, it was concluded that the mobile phone radiation must have caused the testicular organs to undergo a mutagenic change.

A review study has reported that in the past two years, customers use text messages as source of communication more than calls[26]. The effect of text messaging on the human body is however a subject that has not been a studied much. Furthermore, most of the studies performed in this field as animal studies and very few human studies have not been considered. The data that is received from humans is dependent on recall bias. When the in vitro study is performed on granulosa cells and human sperm, this setting does not accurately represent the effect because the mobile phone and the reproductive organs are separated by layers of tissue in real life situations. Therefore, there is a pressing need to modulate the experimental conditions that are close to real situation. It is also important to isolate the mobile phone radiation from environmental factors that can affect its function.

III. CONCLUSION

Various studies investigating the possible effect of mobile phone radiation on humans have been performed. In this paper, five of these effects were reviewed. Most of the studies indicate that mobile phones do have a negative impact on the human body. However, a few studies state otherwise. Most of these studies have been carried out on animals and not on humans which makes these studies unreliable to some extent. The data collected from humans are subject to their ability to recall and can also be classified as biased. Therefore, it is essential that more studies must be conducted in order to validate the previous studies and also to investigate the harmful effects that use of mobile phones can cause. In order for better results to emerge, experimental conditions that mimic real life cell phone exposure must be used for research. Additionally, further research on methods to reduce or limit the radiation exposure on human body must be carried out.

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