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A Review of the Effect of Non-ionizing Microwave Radiation on Human Health

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ABSTRACT

The rapidly increasing concern of non-ionizing microwave radiations affecting human health adversely has been gaining much of attention. A large volume of research studies have been published in the past decade. Most of the previous review literature in this key research area are limited to a certain domain leading to questionable gaps that still need to be filled. This paper, therefore, investigates and analyses all possible gaps, which are left in recent literature related to this issue and aims to provide an inclusive up-to-date overview of evidences and epidemiological studies on different parts of human body, in both adult and children. Based on the literature review, it is evident that the rise in the Specific Absorption Rate (SAR) above its maximum value due to the exposure from non-ionizing radiation can cause severe effect on human body such as a cataract formation in the eye, a shortfall in sperm count in men etc. Specific Anthropomorphic Mannequin (SAM) model, which is used as a certification technique for cell phone, is found to be overestimating the adult and child head exposure by using same geometric model for child and adult head types. It has also been observed that the electromagnetic radiation has both positive and negative effect on the human life, depending on the context of its application. It is envisaged that human can gain from the positive side and avoid the negative effect. A step by step example of numerical simulation model is illustrated to support future researchers in developing further work in this research area.

Keywords: Base station; Electromagnetic fields; Mobile communication; Specific absorption rate; Temperature distribution

1. Introduction

There is a phenomenal increase in the use of microwave electromagnetic radiation in areas like telecommunication, medical, industrial etc. The microwave radiation has a wavelength ranging from 1m down to 1mm, with frequencies between 300 MHz and 300 GHz. Mobile phones emit radio waves working on microwave channels mostly on 900 MHz and 1800 MHz in the market. Setting these massive microwave channels in

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public environment is a big challenge, especially in an undeveloped area, which requires some essential factors and techniques [1, 2]. A fixed station in a cellular wireless network used for communicating with mobile units is called base station. The geographic region, which is served by the base station is called the cell. Base stations in urban areas having high population density operate wirelessly at less power than those situated in a rural area where the distance among the base stations is larger [3].

The use of mobile phone, Wi-Fi, and other radio frequency emitting devices has increased tremendously in the past decade due to the remarkable development of smart device technology. Along with the increment of this technology, concern regarding the health of people who use these devices in excess or who live near transmission power lines or who work with EM radiation emitting machines in industries are also found to be increasing. The non-ionizing radiation is transferred to the biological system when they interact with each other. A question has been raised "does the energy it transfer leads to adverse health effect in human?" Many researchers have attempted to answer the above question by adopting guideline data from following agencies which has been used as benchmarking references to verify the simulation results. International Agency for Research on Cancer (IARC) is a part of World Health Organization, both have classified radiofrequency electromagnetic fields as possibly carcinogenic to humans (Group 2B) [4]. Various organizations in the world such as ICNIRP, IEEE have established safety guidelines for electromagnetic wave absorption [5, 6].

There are theoretical and experimental data that shows long-term exposure to relatively weak static, and low-frequency magnetic fields can change radical concentration in a human body which may cause damage to an important biological molecule and can also affect the translation and transcription of DNA [7]. Following are the three factors considered to affect the human health via cellphone exposure (i) the level of radiation from the cell phone (ii) the duration of exposure and (iii) the age of user [8]. Some epidemiological studies show a significant increase in leukemia in children, who live near power lines and who uses cellphone more frequently [9]. Children are more affected than adults because organism during its evolution is more sensitive to the environmental factors. EM radiation may also disturb the working of medical equipment in hospitals, keeping that in view researchers performed some experiments and according to their obtained data they state that distance up to 300 m from base station is critical to some extent, therefore, it is advisable to do not construct school, hospitals in that area [10, 11].

A survey had been conducted in Nigeria and Malaysia to find out "whether people were unsafe when exposed to base station?" Results show that the propagation of waves depends on the distance and it drops very significantly when we go away from the tower. That means people who live near base station have more chances to get affected [12, 13]. However, the brick walls, reinforced concrete floors, and furniture of houses and buildings act as a shield for people. These materials absorb part of the density of flux from EM waves but on roof people are more exposed to it [14].

Although, there are many negative evidences about the effects of microwave radiation, there still exist a need to conduct more research work in order to confirm these evidences. There have been several studies, which show positive effects of these radiations such as these are useful and being used in medical for cancer treatment, e.g. X-Rays, microwave imaging etc. They are used in microwave ovens and it is reported that the food cooked in a microwave oven is not a radiated hazard [15].

From many years this topic has been the center of interest, number of review papers are published in this area. Despite author's knowledge there seems to be an absence of a comprehensive paper which could be considered as a single reference to review. Hence, in this paper, we tried to cover the different aspects of the effect of electromagnetic radiation on the human health. This paper is organized as follows- Section 2 shows case study of some experiments performing different parts of the human body when exposed to non-ionizing electromagnetic radiation. Section 3 shows the effect of electromagnetic radiation on equipment. Section 4 discusses the positive effects of EM radiation in our life. In Section 5, possible protection technique from electromagnetic waves are discussed. In Section 6, a numerical example is implemented to show the effect of mobile phone radiation on human head. Finally, concluded remarks are discussed and future trends are illustrated in Section 7.

2. Severe Effects of Microwave Radiation on Human

2.1 Mobile Phones Effects

The first mobile phone call was made in 1973 by Martin Cooper, a former Motorola inventor [16]. Since then, it has become an essential and vital part of our life. Several effects have been reported like insomnia, headache, leukemia, and confusion in human who uses mobile phone in excess. There have been many studies performed by researchers to understand the actual reason behind it. This leads us to divide the reported results into four categories.

2.1.1 Effect on Human Head

Electromagnetic energy absorbed by human tissue is measured in terms of Specific Absorption Rate (SAR). It is power absorbed per mass of tissue. Maximum SAR level emitted by cell phone is decided by regulating authorities in different countries. According to Federal Communications commission (FCC), in the USA, maximum SAR for a cell phone is limited to 1.6 W/kg which is taken over the volume containing a mass of 1 gram of tissue that is absorbing the most radiation wave. International commission on Non- Ionizing Radiation Protection (ICNIRP) guideline is widely adopted in Europe which accept the maximum limit of 2 W/kg of SAR taken over 10 gram of tissue. While talking on a cell phone device, head is the nearest region which is exposed to EM radiation as shown in Fig. 1. There are studies which [17-19] calculates the value of SAR and temperature distribution in a human head model, when the head is exposed to mobile phone radiation. It is evident that the temperature distribution in a tissue is not directly related to SAR, it also depends on the effects of dielectric properties, thermal properties, blood perfusion, and penetration depth of the EM power. It has been stated that smaller frequency penetrates longer in tissue because they have higher wavelength. The resultant value of SAR and temperature distribution in the above mentioned studies when the radiating power was assumed 1W, were well below the limited value. Whereas, when the radiating power was increased to 1.5W at the 900 MHz frequency [19], the SAR and temperature distribution value exceeded the limited value. Which may cause harmful effect on human health. Wessapan and colleagues used Finite Element Method (FEM) technique for determining the SAR and temperature distribution in human head. Other than that many researches have also used Finite Difference Time Domain method

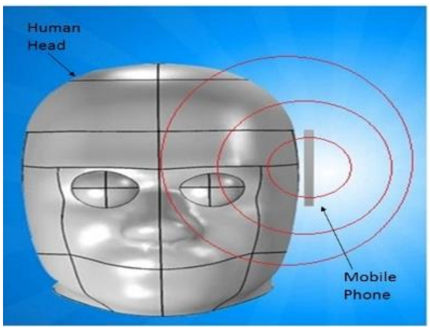


Fig. 1. Human head exposed to mobile phone radiation

Table 1. Numerical methods performed on human head exposed to mobile phone radiation.

Reference	Objective	Frequency/power density used	Mathematical model	Numerical methods	Result
Wessapan et al. [17]	To find out SAR and Temperature distribution in human head	900 MHz, 1800 MHz/ 1W	Maxwell equation [35], Penne's bio heat equation [36]	FEM	Nothing exceed. Not harmful.
Wessapan et al. [19]	To find out SAR and Temperature distribution in human head	900 MHz/ 1W	Maxwell equation , Penne's bio heat equation	FEM	SAR exceeds the limited value at 1.5 W power. Child head is more sensitive to EM radiation than adult's head.
Chou et al. [24]	To reduce the peak SAR for handsets with monopole type antenna through R-cards.	1800 MHz/ 125mW	Formula for the Surface impedance of R cards, SAR calculation formula.	FITD	It was observed that in numerical analysis as well in real measurement minimum SAR reduction factor was 60% for monopole type antenna using R-cards.

(FDTD) [20-23], and Finite Integration in Time Domain (FITD) methods [24] for showing SAR and temperature distribution in human tissue. Effect of near field and far field exposure of mobile phones [25] and the influence of different mobile models on SAR and temperature increase in human head have also been discussed [26, 27]. It is concluded that chronic exposure to mobile phone radiation on human head, could cause adverse health effect, especially on children, the younger the child, the higher the risk. Children absorb more microwave radiation, this topic has been briefly discussed in section 2.1.4. Methods and models of above discussed studies are described in Table 1

2.1.2 Effect on Human Eye

The human eye is daily exposed to EM radiation from different sources in our environment. It is one of the most sensitive part of human body. A small temperature increase of 3- 4 °C can cause Cataracts formation in the eye. According to ICNIRP, the maximum value of SAR for human eye is 2 W/kg (general public exposure) and 10 W/kg (occupational exposure)[5]. Wessapan et al. [28] , investigated the SAR and temperature distribution within the human eye when exposed to EM radiation. Initially, they exposed a heterogeneous human eye model to an EM radiation device which was working at 900 MHz frequency, the highest value of SAR, was obtained in cornea (135.15 W/kg) exceeding the limited value. Later on, they perform the same study with two radiating frequency 900 MHz and 1800 MHz [29]. This time at the 1800 MHz, both SAR (45.9 W/kg) and temperature distribution (3.33°C) exceeded the limited value. Which may lead to formation of cataract or posterior capsular opacification. They also tried to find out, does the ambient temperature [30] and the position of human eye [31] effect the SAR and temperature distribution inside human eye. They concluded that human eye may face some serious danger in case of ambient temperature, whereas there is no effect of body position (siting, supine, and prone) on SAR and temperature distribution. Not only wessapan et al., several other researches have also showed the heat transfer in human eye when it is exposed to EM radiation [32-34]. Methods and results of some studies are discussed in Table 2.

2.1.3 Effect on Adult's Reproductive System

Men usually carry mobile phones in their trouser pocket or in some kind of holders (clipped to their belts or waist) as

Table 2. Numerical methods performed on the human eye when exposed to EM radiation**.**

References	Objective	Frequency/ power density used	Mathematical model	Numerical methods	Results
Wessapan et al. [28]	To find out SAR and Temperature increase in human eye.	900 MHz/ 5mW/cm^2, 10mW/cm^2, 50mW/cm^2, 100mW/cm^2.	Natural convection, Porous media theory, Maxwell's equation, Penne's bio heat equation.	FEM	SAR value exceeded the ICNIRP limit.
Wessapan et al. [29]	To find out SAR and Temperature increase in human eye	900MHz, 1800MHz/ 100mW/cm^2.	Natural convection, Porous media theory, Maxwell's equation, Penne's bio heat equation.	FEM	SAR and temperature both exceeded the limited value.
Wessapan et al. [30]	To find out SAR and Temperature increase in human eye.	900MHz/ 100mW/cm^2.	Natural convection, Porous media theory, Maxwell's equation. Penne's bio heat equation.	FEM	SAR and Temperature exceeded the limited value. Ambient temperature effect the results.
Wessapan et al. [31]	To find out SAR and Temperature increase in human eye in different body position.	900MHz, 1800MHz/ 100mW/cm^2.	Natural convection, Porous media theory, Maxwell's equation, Penne's bio heat equation.	FEM	No effect of body position on the value of SAR and temperature. Both exceeded the limited value in each condition.
Hirata et al. [34]	To find out SAR and temperature increase in human eye.	600MHz-6GHz/ 5Mw/cm^2	Penne's bioheat equation.	FDTD	Below danger level.
Buccella et. al [32]	To find out the temperature and SAR increase in human eye.	1, 1.9, 2.45 GHz/ 5mW/cm^2.	Bio heat equation, time harmonic electromagnetic field.	FDTD	Below danger level.

shown in Fig. 2, close to their reproductive organs while using hand free devices such as Bluetooth, head phones etc. The concern about the use of hand held cellular telephones in adults and their impact in causing some adverse effect, for instance: brain tumor, difficulty in concentration, disturbance in sleep, headache, and reduction of melatonin and sperm count in human have been widely debated [37]. An investigation was performed by dividing 361 men into 4 groups according to their usage of mobile- [i] no use [ii] less than 2 h/day [iii] 2-4 h/day and [iv] more than 4 h/day. The result showed that regular use of cell phone adversely affect the quality of semen by decreasing the sperm counts, viability, motility, and morphology, which might contribute to male infertility [37-39].

Fig. 1. Man tucking his cell phone near his reproductive system**.**

However, a vitro pilot study failed to show significant DNA damage after one hour of cell phone exposure [40, 41]. Recent studies claim that there is a detrimental effect of cell phone on sperm parameters leading to decreased male fertility. Nonetheless, there are just as many studies that show no correlation link between the cell phones and semen parameters [42]. The effect of cell phone on the semen quality has not been extensively addressed. A study performed on 782 patients in 4 different hospitals showed that there is no evidence of causing brain tumor or malignant by using hand held cellular telephone [43]. However, the effect of cellphones causing tumor is not entirely known, there is still limited data on non- ionizing frequency radiation causing cancer and tumors in human.

Heat generated by the portable devices interact with the genital area of human while using them on lap. Wessapan et al. [44], have recently investigated the SAR and temperature distribution in human testicular and its related tissues. Their result showed that at the operating frequency of 900 MHz and 1800 MHz at the radiated power 10 W, maximum SAR value was found in the penis and skin which exceeded the limited value of ICNIRP general public exposure.

In women, breast cancer is one of the most common cancers increasing by 0.5% annually worldwide. Microwave imaging technique is preferred for its treatment over X-ray mammography, as it is non- ionizing technique [45]. It has been seen, some women carry their mobile phones in their bras. Apple iPhone™ 4 user guide has clearly said to do not keep iPhone™ in bra pocket [46], as it could be harmful. An investigation was performed on 4 women having age 21 to 39. These women regularly tucked their mobile phones against their breasts in their bras, every time while jogging, working, and traveling for around 10 hours a day for several years. That developed a tumor in the areas of their breast immediately underlying the cell phone. This multifocal invasive breast cancer arises the concern of a possible association with the non- ionizing radiation which was emitting from the cell phone [47].

Fig. 2. EM radiation emitting toys.

2.1.4 Effect on Children's Health

Electronic and computer devices such as smart watches, smart toys, tablets, mobile phone as shown in fig. 3 play an important role in raising children in the modern society. These devices emit EM radiation which could be potentially harmful for children health.

There are multiple studies showing the higher value of SAR in child's head than adult when exposed to cell phone radiation [19, 48]. Every cell phone manual has warned that the phone should be kept at various distances from the body otherwise the human exposure limits can be exceeded. iPhone™ 5 has an inbuilt guideline (user can go to the settings ➤ generals ➤ about ➤ legal ➤ RF exposure) which instruct us to carry iPhone™ at least 10 mm away or better to use hand free devices such as earphones, built-in speakers etc. [46].

According to FCC, the minimum of 20 cm distance should be maintained between a user and gadgets (laptop, tablets etc.). This contradicts the normal operating position, for example: laptop users usually use them on laps and hence, cannot meet the 20 cm restriction. Also, children have small arms which do not allow them to keep the device 20 cm away from their body. Nevertheless, there are no specific guidelines for children exposure to EM radiation [49]. Specific Anthropomorphic Mannequin (SAM) is a technique which has been used for the cell phone certification process for determining the SAR value of a mobile user [49, 50]. The human head model which is used in this technique is known as SAM model. This SAM technique have some drawbacks such as (i) there is no separate SAM model for infants and toddlers, the size, skin and, bone layers of a child head are thin, it means head smaller than this SAM model will absorb more radiation (ii) the fluid used for the SAM process does not differentiate in child and adult head properties (iii) this process is not tested on the places where cell phone users usually keep their phone while using hand-free devices like in their shirt pockets or in their trousers. Therefore, this SAM process is not worthy and should be revised or discontinued.

2.2 Effects from Industrial Machines Emitting Radiation

Electromagnetic energy has been used on a large scale in many industries. When electromagnetic waves penetrate any surface, it is converted into thermal energy within the material volumetrically. Due to its characteristics, microwave heating is used in industries and in many household applications. There is a public concern about the health of the workers, working in the industry and surrounded by this radiation from all side. Wessapan et al. [51], investigated the SAR and temperature distribution within various layers of tissue in human body, when exposed to EM radiation emitting from industrial machines. A human model [52] was exposed to 1900 MHz and 2450 MHz frequencies. Results obtained showed that maximum SAR obtained was in the skin for both frequencies, exceeding the limited value. It is reported that that the SAR and temperature distribution is greater in human tissue when EM wave propagation is in TE mode [53,54]. The standing wave phenomenon has been observed when a dielectric shield is placed in front of human model to protect it from the incident radiation. The standing waves are form by low frequency waves with the combination of incident and reflected waves between the dielectric shield material and human body. Hence, in some cases they increases the SAR and temperature distribution inside human body when the body is shielded, the values were above the limited value and may cause harmful effect on human health [18, 55]. This suggests workers should not be much active in the area where high EM radiation emitting machines are placed. Results of their research are described in Table 3.

Table 3. Numerical methods performed to find out SAR and temperature distribution on a human body exposed to EM radiation emitting from industrial machines.

References	Objective	Frequency/ power density used	Mathematical model	Numerical methods	Results
Wessapan et al.[51]	To find out SAR and Temperature distribution in a human body	915MHz, 2450MHz/ 5mW/cm^2, 10mW/cm^2, 50mW/cm^2.	Maxwell's equation, Penne's bio heat equation	FEM	SAR exceeded, temperature distribution was below limited value.
Siriwitpreecha et al. [53]	To find out SAR and Temperature distribution in a human body.	915MHz, 2450MHz/ 10mW/cm^2, 50mW/cm^2, 100mW/cm^2.	Maxwell's equation, Penne's bio heat equation	FEM	SAR exceeded, temperature was under limited value. SAR and Temperature was greater in TE mode than TM mode.
Siriwitpreecha et al. [54]	To find out SAR and Temperature distribution in a human body.	300MHz, 915MHz, 1300MHz, 2450MHz/ 100W	Maxwell's equation, Penne's bio heat equation	FEM	SAR exceeded the value, temperature was below limited value.
Wessapan et al. [55]	Effect of dielectric shield on SAR and Temperature in human body.	300MHz, 915MHz, 1300MHz, 2450MHz/ 5mW/cm^2	Maxwell's equation, Penne's bio heat equation	FEM	SAR and Temperature was greater in shielded case at some frequencies.

2.3 Effect from overhead transmission line

There is a concern of adverse health effect on human health for those who lives in the vicinity of EHV transmission lines shown in Fig. 4 and get exposed to electric and magnetic fields. One reason behind it is, AC electric and magnetic field induce surface charges on biological bodies, which causes a flow of weak current in human bodies that lead to harmful effect. S.M.El-Makkawy [56] performed a computational analysis to find out the electric distribution on human body standing beneath a 380 kV 3-phase 50 Hz high voltage overhead transmission line. Results obtained showed that induced current density increases along the length of the body starting from head to legs, except neck due to the increase in surface electric field. The induced current increases when the distance between the human body and transmission line decreases. The value of induced current in all cases was well below limited value (1mA). It was so small that it could only cause slight tingling sensation on hands or fingers. Several methods have been used to calculate the current density and related induced field in the human body when exposed to high voltage transmission line. Maria et al. [57] used Finite difference time domain method (FDTD) and Scalar potential finite difference (SPFD) methods for calculating electric field distribution and magnetic induction on a human body, respectively. Nabil et al. [58] investigate the induced electric field and current density on a worker standing 2 m away from conductor phase C of a double circuit 132 kV 60 Hz transmission line in Riyadh region of Saudi Arabia. Results obtained for external electric field and an external magnetic field was 6485 V/m and 66.4 µT, respectively. the values obtained were well below the limited value set by IEEE [6]. The maximum induced electric field in brain and heart were below the IEEE standard. The maximum induced current densities in all tissue were also below the ICNIRP limit. Table 4 concludes the results of investigation.

Fig. 3. Picture of overhead transmission lines**.**

Table 4. Numerical methods performed on human model exposed to Over Head Transmission Lines.

References	Objective	Numerical methods	Result
S.M.El-Makkawy [56]	To find out Electric field induced current on grounded human body standing beneath HV transmission line.	A computer program, based on the boundary element method (BEM).	The value of induced current was below the limited value.
Maria et al. [57]	To find out the induced currents by 60Hz Electric and Magnetic fields in a human model.	FDTD, SPFD.	Organ average, organ maximum and spatial maps of the induced electric and current density fields were obtained.
Nabil et al. [58]	To find out induced Electric fields and current in human body.	Charge simulation method, Biot-Savart law, FDTD.	External electric and external magnetic field were below the limited value.

Table 5. Numerical methods performed to find out the effects of Wi-Fi radiation on human.

References	Objective	Numerical methods	Results
Wessapan et al. [59]	To investigate the SAR and temperature distribution in a biological tissue exposed to near field radiation.	FEM	SAR exceeded the limited value for 0.5cm and 1cm distance
Hikma et al. [60]	To find out Electric field intensity and SAR in a human model exposed to Wi-LAN Base station.	FDTD	Although, it was safe, long time exposure may cause harmful effects.

2.4 Effects from Wi-Fi Radiation

Electronic devices are getting wireless making human life less messy, more easy, and smart. Wireless devices such as mobile phones, portable wireless router, and other wireless devices emits radiations, it can be near filed or far field. Any system that uses IEEE 802.11 standard comes in the category of Wi-Fi. Harmful effect from these radiation is a topic of concern. Recently an investigation was performed to calculate the SAR, fluid flow and temperature distribution in the biological tissue exposed to near field EM radiation [59]. The effect of distance to the EM emitting source and tissue permeability on natural convection in the biological tissue are systematically investigated. Results showed that SAR, electric field intensity, heat generation, and temperature, increases within the tissue as the distance between tissue and antenna decreases. Maximum SAR was found beneath the antenna. Hika et al., [60] calculated electric field intensities from wireless LAN at IIUM Campus, Malaysia. Maximum SAR was found in the skin, while lowest SAR was in bladder of a human body. It was just the 14.6% and 0.19% part of the recommended safety limits. It was safe but long time exposure of it may cause harmful effects. A test was performed on 30 mice exposed to far field EM radiation. The Antenna was set to 2.4 GHz frequency and placed at 1m distance from the cage of the mice. Mice were exposed to radiation daily for 8 hours and for 6 months period. After this, they were sent to veterinary laboratory for the test. Results show that some tissues of liver, brain, and lungs degenerate, which indicates the harmful effect from Wi-Fi radiation [61]. Results are illustrated in Table 5.

2.5 Effects from Cellphone Tower

Base station antenna emits high Electromagnetic radiation, but SAR absorbed by human tissue is greater when exposed to mobile phone radiation due to its shorter distance to human body [62]. Effect of GSM (100 watt) base station on human head was investigated by Md. Faruk Ali et al. [63]. Base station antenna was placed at different distances between 0.5 m to 5 m and was operating at 925 MHz frequency. When the antenna was placed at less than 1 m distance from head model, the maximum SAR calculated with respect to human head model in skin and bone tissue exceeded the limited value. For distance greater than or equal to 1m, SAR value obtained was below the limited value. An investigation was performed in south west side of Kolhapur (India) [64] to measure the EM radiation in terms of power density and electric field at the region near the base station antenna. The base station tower was 150 feet mounted on ground and having nearly 16 to 20 antennas. Measurement was done in the area of 10 m to 50 m. An instrument called “Three axes field strength meter KM 195” was used for the measurement in around 50 homes (in their hall, kitchens, bedroom and roof). Results show Power densities were low in hall, medium in bedroom, high in balcony and rooftops of the houses. Power densities exceeded the limited value near the base station and it decreases as the distance increases. The results of the effect of GSM on human are concluded in Table 6.

3. Severe Effect of Radio Frequency Radiation on Equipment

Electromagnetic compatibility is a branch of electrical engineering which deals with the concern that a device is compatible with its electromagnetic environment, and the radiations emitted by it does not affect adversely to other devices in its vicinity. Radiations coming from base station antennas, cellular phones may affect the working of medical devices, radio amateurs etc. This is totally contrary to electromagnetic compatibility regulation [11]. Base stations built on hospital buildings, near clinics, residential area could be the cause of Electromagnetic interference. This shows the lack of EMC knowledge to the people who manufacture, install and maintain the working of base stations. People who carries cell phones in their shirt's pocket make close contact with the pacemaker.

Yoshiaki et al. [65] constructed a torso phantom and installed a pacemaker in it. A cell phone of 900 MHz band was used with maximum antenna input of 0.8W. The result showed that the malfunction in pacemaker depends on the distance, as the distance between pacemaker and phone decreases the EMI increases. The pacemaker committee of japan decided that all type of pacemaker should be checked to establish guideline for pacemaker user. In the iPhone™ guideline, it is mentioned that pacemaker users always use ear opposite to the pacemaker and maintain a distance of minimum 6inches to avoid potential interference with the pacemaker [46].

4. Positive Effect of Non-ionizing Microwave Radiation

Microwaves have become an essential part of our society by making our life simpler and easier. They are being used in the area of communication such as in cell phones, Wi-Fi, televisions, Radar, Bluetooth devices, FM radio. They have been used in medical treatments for over 75 years. They are used in the operation of medical resonance imaging (MRI) for obtaining 3D images, in microwave ablation (RFA) to destroy cancer cells [66], in microwave imaging for detecting breast cancer [67], wound healing, bone healing, etc. The microwave imaging technique is very popular among patients because both ionizing radiation and breast compressions are avoided in it [68-72]. Microwave radiation is also being used in microwave ovens, they are used in electronic gadgets like virtual reality headsets etc.

5. Protection Techniques from Microwave exposure

Along with the rise in people's concern for safety rose the market's claims in regards to the EM radiations in their products. They assure that their products would protect their users from EM radiations and so they make their products visibly attractive online, some of these products are- (i) Pong cases for iPhones™ [73] (ii) Aamoraa EMF Balancer for Phones™ [74] and, (iii) Shieldite [75].

Table 6. Numerical methods to find out effect of cell phone tower on human.

References	Objective	Numerical methods	Result
Md. Faruk Ali et al. [63]	To find the SAR in a human head model exposed to mobile base station antenna.	Friis transmission equation combined with Finite difference in time domain.	SAR value depends on the distance to the antenna.
Amar Renke et al. [64]	To investigate the residential exposure to EM field from base station.	EM field exposure was measured with the help of three-axis EM field meter model KM-195	Power density was maximum near antenna and decreases as distance increases.

There have been no scientific proof to verify these claims nor have there been any research papers in their favor. Other than these kind of products, there are some suggestions which has been given to people for reducing EM exposure.

- It is advisable to avoid cell phones as much as possible, for instance- keep it away from you while sleeping to protect yourself from EM radiations.
- There are some people who tend to stay around the ovens whenever cooking/heating something. This also exposes them to some EM radiations and can be easily preventable by standing away from the microwaves while cooking.
- It has been seen, some ladies tuck their phones near their breasts that might cause tissue heating which might lead to tissue damage.
- It is recommended to use hand free devices like earphones to reduce the SAR level from direct contact of cell phone.
- Men may not keep their phone in their pants near their reproductive system that might cause reduction in the sperm motility.
- People are highly recommended to follow the guidelines of mobile phone. The iPhone™ guideline says to keep the phone at least 6 inches away while talking.

6. Numerical Example

This section presents a step by step example of numerical simulation model implemented in COMSOL 4. 4, for determining the SAR and temperature distribution in a human head model. The model is exposed to a mobile phone, operating at 835 MHz frequency with the radiated power of 13 W.

Step 1: Set up Model Environment

In this study, a simulation is performed in three dimension space using bio heat transfer and electromagnetic waves frequency domain module using frequency domain and stationary study.

Step 2: Create Geometric object

A three- dimension geometry of a human head model is used and it can be obtained from [77].

Step 3: Specify Material properties in COMSOL Multiphysics

Electrical data of biological tissues (in this simulation only in brain) is set for the human head geometry.

Step 4: **Define Physic Equations**

In this step a suitable set of equations and boundary conditions are used for the geometry, which can be described as follows:

(A) Equations for Electromagnetic Wave Propagation Analysis

Maxwell's equation used for the electromagnetic wave propagation in the human head is expressed in Eq. (5.1).

$$\nabla \times \frac{1}{\mu_r} \Delta \times \boldsymbol{E} - \boldsymbol{k_0^2}\ \boldsymbol{\mathcal{E}_r E} = \boldsymbol{0} \qquad (5.1)$$

Where E is electric field intensity (V/m), μ_r is relative magnetic permeability, $\mathcal{E}_r$ is relative dielectric constant, and K_0 is the free space wave number (m^{-1}).

EM energy is emitted by patch antenna and strikes the human head with a particular radiated power. Therefore, lumped port boundary condition is included which is applied to the patch of the antenna and is shown in Eq. (5.2).

$$\boldsymbol{Z_{in}} = \frac{\boldsymbol{V_1}}{\boldsymbol{I_1}} \qquad (5.2)$$

Where Z_{in} is the input impedance (ohm),

V_1 is the voltage along the edges (V). I_1 is the electric current magnitude (A).

The perfect electric conductor boundary condition considered along the patches on the antenna and is expressed in Eq. (5.3)

$$\boldsymbol{n} \times \boldsymbol{E} = \boldsymbol{0} \qquad (5.3)$$

The scattering boundary condition applied to the outer space of calculated domain i.e. free space can be found in Eq.(5.4)

$$\boldsymbol{n} \times (\boldsymbol{\nabla} \times \boldsymbol{E}) - \boldsymbol{jkn} \times (\boldsymbol{E} \times \boldsymbol{n}) = -\boldsymbol{n} \times \left(\boldsymbol{E_0} \times \boldsymbol{jk}(\boldsymbol{n} - \boldsymbol{k})\right)\boldsymbol{exp}(-\boldsymbol{jk}.\boldsymbol{r}) \qquad (5.4)$$

Where k is the wave number (m^{-1}), n is the normal vector, j=$\sqrt{-1}$, and E_0 is the incident plane wave (V/m).

(B) Equations for Heat Transfer Analysis

The Penne's' bio heat equation is used to obtain the temperature distribution within the human head as shown in Eq. (5.5)

$$\boldsymbol{\rho C}\frac{\boldsymbol{\partial T}}{\boldsymbol{\partial t}} = \boldsymbol{\nabla}.(\boldsymbol{k\nabla T}) + \boldsymbol{\rho_b C_b \omega_b}(\boldsymbol{T_b} - \boldsymbol{T}) + \boldsymbol{Q_{met}} + \boldsymbol{Q_{ext}} \qquad (5.5)$$

Where $\boldsymbol{\rho}$ is the tissue density (kg/m^3), C is the heat capacity of tissue (j/kg K), k is thermal conductivity of tissue (W/m K), T is the tissue temperature (°C) , T_b is the temperature of blood (°C), ρ_b is the density of blood (kg/m^3), C_b is the heat capacity of blood (3960 J/ kg K) , ω_b is the blood perfusion rate (1/s), Q_{met} is the metabolism heat source (W/m^3), and Q_{ext} is the external heat source (electromagnetic heat- source density) (W/m^3).

The thermally insulated boundary condition applied to the outer surface of human head is expressed in Eq. (5.6)

$$\boldsymbol{n}.(\boldsymbol{k\nabla T}) = \boldsymbol{0} \qquad (5.6)$$

(C) Equations for heat transfer analysis

The absorbed electromagnetic energy by tissue is measured in terms of SAR. It is power absorbed per mass of tissue. The specific absorption rate is described by the following equation:

$$\mathbf{SAR} = \frac{\boldsymbol{\sigma}}{\boldsymbol{\rho}} \, |\boldsymbol{E}|^{\mathbf{2}} \qquad (5.7)$$

Where E is root mean square electric-field (V/m), σ is electric conductivity (S/m), and ρ is the tissue density (kg/m^3).

Step 5: Meshing

For meshing the geometry, COMSOL Multiphysics software have (i) user-controlled mesh and (ii) physics controlled mesh options. In this simulation, the user-controlled mesh is chosen with normal element size. Free triangular and free tetrahedral meshes are applied to the different boundaries of geometry.

Step 6: Verification of the model

In order to get published any new finding by the researcher it is must to verify and validate the results before that. However, this section is just describing a step by step demonstration of numerical example with an intention of giving an idea to the readers on how the simulation can be performed. We are here giving you a brief information about how verification of a simulation can be done. To verify the accuracy of the present numerical model, we can choose one of the previously published papers. The previously published study should be calculating the same parameters which you are calculating in your present simulation. Afterwards, to verify the accuracy of the present numerical model, validate the modified case of the simulated result against the numerical result with the same geometric model mentioned in the previous paper. We can also validate our present simulation by performing an experimental analysis, such as we can use thermal cameras and a real human body. The human body is exposed to the mobile phone radiation, all the parameters of the real mobile phone and that used in the simulation should be same. We can then calculate the SAR and temperature distribution in the real human head by using thermal cameras.

Step 7: Execution of the Program

Press the compute icon under study tab to execute the simulation model.

Step 8: Post process Result

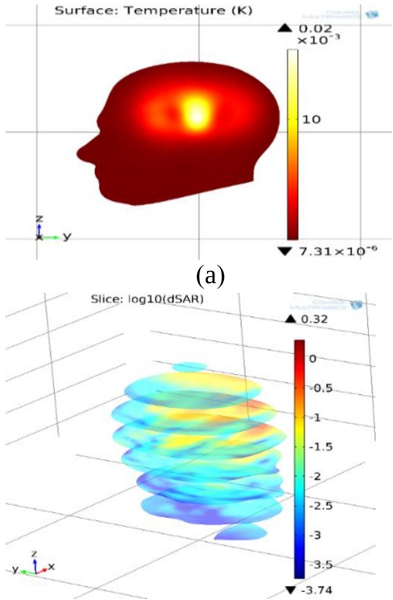
After execution of the model, line graphs, surface plot and slice plot are plotted for SAR and electric field distribution in the human head geometry. The resultant figures of the simulation are shown in Fig. 5. It illustrates temperature distribution and SAR distribution in a human head model. It is clearly seen the hot region where temperature is maximum in the middle of head as shown in Fig. 5 (a). The SAR is highest near the region of mobile phone and then the SAR value decreases as the distance inside head increases as shown in Fig. 5 (b).

An extrusion line as shown in Fig. 6 is considered at X= 0, 0; Y=0.08, -0.12; Z= 0.02, 0.02 points. The graphs of SAR and electric field distribution are plotted along this line. The resultant graphs are shown in Fig. 7.

Fig. 7 (a), in case of electric field distribution the highest value obtained in the region of brain is 20 (V/m) at 0.07 (m) and then it slowly decreases along the arc-length. In the case of SAR distribution in Fig. 7 (b), the highest value in the brain region is 0.13 (W/kg) and then it also decreases along the arc-length. However, resultant values does not exceed the ICNIRP limited value of 2 W/kg.

For verifying the accuracy of the numerical model, we can choose one published paper which is calculating the same parameters as ours. The published paper is try to simulate step by step, the modified case of the present simulated results is then can be validated against the previous published paper.

For implementing this simulation COMSOL™ Multiphysics software has been chosen due to its strength against other commercial packages in terms of solution accuracy and consistency. COMSOL™ has predefined CAD geometries and provides us the ability to define our own partial differential equations. However, it may not fit for industrial use. Software like Ansys are more often used in industrial sector.



(a)

(b)

Fig. 5. Result arising from computation using COMSOL
(a) Temperature distribution in human head.
(b) SAR distribution in human head

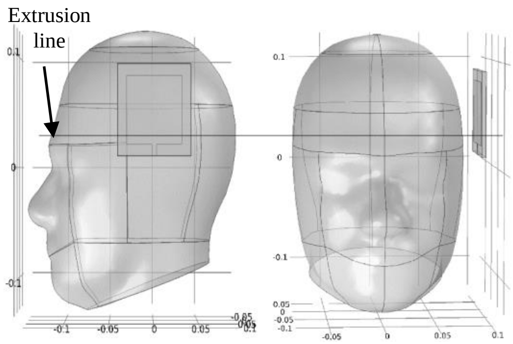
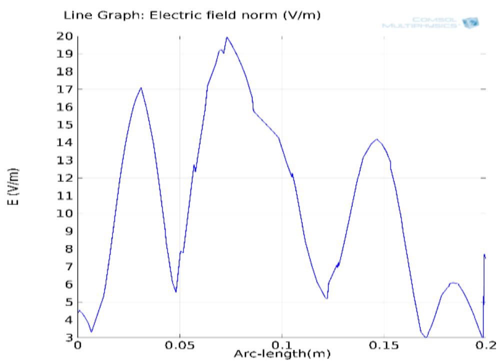
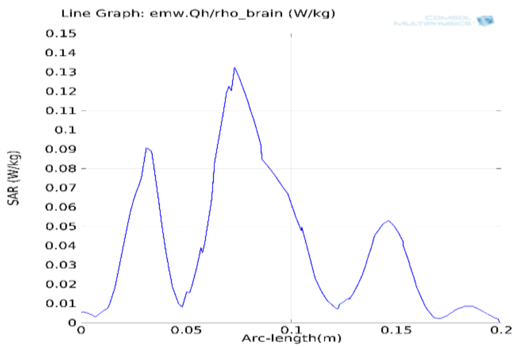


Fig. 6. The extrusion line in the human head where the SAR and electric field distribution are considered.



(a)



(b)

Fig. 7. Post process result
(a) Electric field distribution
(b) SAR distribution in the human head

7. Conclusion and Future Work

In this paper, evidences and epidemiological studies are reviewed and discussed to understand the effect of radio frequency radiation on human health. This research work was motivated by the fact that people are concerned about the danger of microwave radiations and are therefore afraid of using cell phones and other domestic appliances. We categorize our research paper in sections to understand the different common sources which emits EM radiation and to whom people are being exposed repeatedly. We have reviewed number of research papers, along with relevant governmental and other policy documents, manufacturers' manuals and similar documents related to this area. In our conclusion of literature review we found that EM waves might exert influences on biological functions of cells and tissues. It is hard to come to a conclusions that EM radiations are causing adverse effect on human health, because, it necessitates strong evidences and the need of long time research. To support the evidences that we have studied in our literature review, we have performed a simulation example that calculates temperature and SAR distribution in a human head model, when the head is exposed to mobile phone radiation. The resultant values of SAR and temperature distribution in our simulation were below the limited value but it is considered that long time exposure of this radiation may cause harmful effects. There are many studies which show positive effect of EM radiation while some studies have shown no effect of EM on human health. It is envisaged that there is a need to conduct more research work to confirm the evidences on the negative side. It has been reported in many studies that children are more sensitive to EM radiations than adults, because, their skull size is smaller and their skin is very thin. The EM emitting devices are openly selling in markets which may increase the chances of negative effect on children health. While writing this paper there are no guidelines published for children exposure to EM radiations. We are planning to make more deep studies regarding the effect of EM radiation effect on children health.

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