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Biological Effect of High Frequency Electromagnetic Radiation – A Review

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Abstract— **In the era of wireless communication, the exposure to electromagnetic radiations is increasing. Most of these radiations fall in the category of microwaves. In addition, domestic appliances and medical treatments also use microwaves for various purposes. At the same time, there are some alleged hazards of the microwaves, which may lead to permanent impairments in the biological system. This paper concentrates on the exposure of microwaves from cellular networks. It describes the energy content, interaction of microwave with biological system, measurement techniques and safety standards. Finally, some suggestions have been made that reduces the exposure of microwave radiations to human body from wireless communicating devices.**

Index Terms— **Dosimetry, ICNIRP, Ionization, SAR (Specific Absorption Rate)**

I. Introduction

In the present times, the association of microwave band devices and biological being is growing at fast pace. The microwave band devices are widely used for communication, household appliances and medical services [1]-[3]. Despite some reported hazards of these electromagnetic waves [4], their applications and hence exposure is increasing constantly. Specifically, microwave radiations are a part of electromagnetic spectrum having frequency range varying from 300MHz to 300GHz. Energy of each quanta in an electromagnetic wave is given by E=hf, where f is the frequency of wave. These high frequency electromagnetic waves (so called microwaves) are categorized as non-ionizing radiations, where as ionization effect associated to UV light, X rays, gamma rays is well known. The ionization in the living beings may leads to damage to the biological tissues. The minimum photon energies capable of producing ionization in water and in atomic carbon, hydrogen, nitrogen, and oxygen are between 10 and 25electron volt. A single photon of radio frequency (RF) radiation, having frequency of 3GHz has relatively low energy level of the order of $1.24x10^{-5}$eV [5]; therefore it is not capable of ionization. Hence, electromagnetic waves used for wireless communication are unable to ionize the matter and under ordinary circumstances are too weak to cause significant damage to biological molecules such as DNA.

Nature contributes a little to the microwaves in the atmosphere and extra terrestrial space due to lightening discharge in thunderstorms. The field strength of atmospheric variations varies approximately inversely with the frequency. These extraterrestrial electromagnetic radiations are very intense, but since it comes from very distant source, the angle subtended by the earth is quite small. Therefore, strength of such fields gets diminished. The electromagnetic waves of frequency range between 30 MHz to 30 GHz do penetrate the atmosphere. Below 30 MHz the ionosphere reflects the radiation back to the space and above 30 GHz attenuation is high except in narrow frequency windows [5]. Among man made microwave generations, the telecommunication transmission is a major source of electromagnetic waves. Also, communication systems operating in HF band (3 MHz - 30 MHz) transmit power as much as 600 kW in the form of electromagnetic waves. In addition, RADAR, satellite communication, navigations systems involve the also use of microwave transmission.

Besides, in domestic use microwave oven produces electromagnetic waves, some part of which may leak out; mostly in case of old or faulty door seals or simple wear and tear. In medical treatment, the uses of microwave techniques have become successful in treatment of tumors [3].

II. MEASUREMENT OF MICROWAVE EXPOSURE

For studies of health effects on people exposed to RF fields it is must to estimates the exposure over time. Instruments have been developed to estimates the exposure using personal exposure monitors worn on the body [6]. The type of monitor has been dependent on the environment to which subject is exposed. Workers on antenna sites have worn pocket-sized devices whereas more sensitive instruments have been developed to capture relatively low level exposures over the general population. The field strength recorded by a body worn instrument may differ from that recorded by the same instrument in the same position with the body absent by up to 10-15 dB; when operating close to body resonance frequencies (few tens of MHz), depending on the direction of incidence and the polarization of the radiation. The accuracy of personal monitors is also affected by non uniformity of field strength over the exposed body. In alternate to the measurement of external electric and magnetic fields, it is also possible to estimate the exposure by measuring currents induced as a result of exposure to RF fields.

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III. DOSIMETRY

The term “Dosimetry” represents the “evaluation of dose” [5]. The field developed internally in the tissue is the primary cause for biological effect due to RF fields. This induced electric field is evaluated and correlated in terms of specific absorption rate (SAR). Specific absorption rate is a measure of the rate at which energy is absorbed by the body when exposed to an electromagnetic field. Quantitatively SAR is defined as the power absorbed per mass of tissue and has units of watts per kilogram (W/kg). Further, microdosimetry refers to the determination of the microscopic distribution of absorbed energy. It deals with the quantitative study of the distributions of EM fields imparted in cellular and sub-cellular biological structures and their relationship to biological effects.

Each mobile communication handset has a radio transmitter and receiver that are manufactured so that exposure limit should not exceed the limits set by the Federal Communications Commission (FCC) or European Union recommendation. The guidelines are based on standards that have been developed by independent scientific organizations through periodic and thorough evaluation of scientific studies. The limit set by the Council of the European Union recommends the SAR limit of 2.0W/kg averaged over 10 g of actual tissue i.e. 0.02 W absorbed in any 10g mass of tissue. The Federal Communication Commission (FCC) requires that phones sold have a SAR level at or below 1.6 watts per kilogram (W/kg) taken over a volume containing a mass of 1 gram of tissue. The output power from a GSM mobile phone varies from 1W peak to 1mW, and consequently SAR varies. Specifically, the SAR ratings of Apple i Phone 4 is as given in table I.

TABLE I
TYPICAL SAR VALUES FOR I-PHONE **[7]**

Apple I phone 4 North America SAR Rating (1.6W/Kg)	
Band	SAR at ear
850	1.00
1900	1.17
UMTS	1.17

To compare SAR with the ICNIRP (International Commission on Non-Ionizing Radiation Protection) basic restriction, the SAR is averaged over a period of 6 minutes. The thermal effect is the dominant established mechanism for biological and health effects associated to RF exposures. Elevation of deep body temperature is closely related to the energy absorption rate in the whole body, when the exposure duration is more than the thermal time constant of the body (>6 minutes). Two areas of the body, the eyes and testis, are known to be particularly susceptible to heating by RF energy because of the relative lack of available blood flow to dissipate the excessive heat [8]. In the case of extremely localized exposures on some body part, significant temperature rise could occur around the exposed part resulting in thermal injury of the tissue regardless of the deep body temperature elevation. Thus, local SAR in the part of the body should be considered in this case.

For longer exposure durations, RF energy-induced temperature rise depends on the target tissue target and their thermal regulatory behavior. For local body exposures, rapid temperature rise and local tissue damage may occur if the amount of RF energy absorbed is excessive. Under moderate conditions, a temperature rise on the order of 1°C in humans can result from an SAR input of 4Wkg-1 and this temperature rise falls within the normal range of human thermoregulatory capacity. Under ambient environmental conditions i.e. at higher temperature and humidity, the same SAR could produce body temperatures that reach well beyond normal levels permitted by the 1°C increment and it could precipitate undesired heat-stress-related responses.

IV. TEMPERATURE RISE CALCULATIONS

Due to lack of blood flow and negligible heat exchange between human eye and surrounding tissue, the human eye is considered as an object thermally isolated from the head. For calculating the temperature rises in the human eye, we use Pennes’ bioheat equation,[9]

$$C\rho\frac{dT}{dt} = K\nabla^2 T - \rho(SAR) - bT \quad (1)$$

Where

T: temperature of the tissue; K: thermal conductivity of tissue; C: specific heat capacity of tissue; B: coefficient associated with blood flow.

The temperature rise averaged over the whole eye and the maximum temperature rise in the eye depends on the frequency of the incident wave as shown in Fig.1. Comparing fig 1and 2, the value of temperature rise averaged over the eye is similar to that of the SAR averaged over the eye, but the value of maximum temperature rise in the eye becomes larger as the frequency is increased.

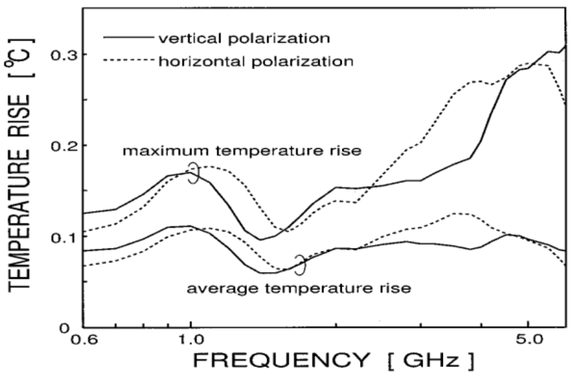

Fig 1: The dependence of temperature rise on the frequency of the incident wave

There are two main reasons for this variation. One is the concentration of energy deposition in the front of the eye. Another is the convection coefficient between the air and the eye is smaller than that between the body core and the eye by a factor of about three. Thus, the heat deposited in the front of the eye is not diffused so much, leading to more temperature rise around lens. Particularly, the relative difference in the maximum temperature rises caused by the EM wave polarizations is about 50% around 3.5 GHz.

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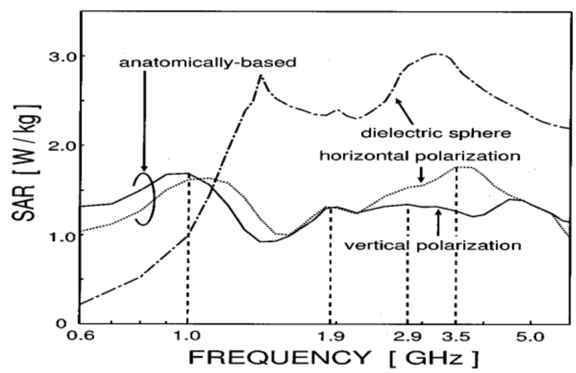

Fig 2: The dependence of the SARs averaged over the eye on the frequency of the incident wave

A range of studies using various mammalian species and human volunteers has established that for RF exposures, the threshold SAR at which reproducible behavioral effects occur is in the range 2 to 4W/kg. Standards for human exposure to RF fields generally reduce the allowable SAR by a factor of 50 (10 as safety factor of for occupational exposures and reduction of 5 for the general public to account for uncertainties in the existing scientific database.

V. SPECIFIC ABSORPTION RATE CALCULATION

SAR can be calculated from the electric field within the tissue as:

$$\mathrm{SAR} = \int_{\mathrm{sample}} \frac{\sigma(\mathbf{r})|\mathbf{E}(\mathbf{r})|^2}{\rho(\mathbf{r})} d\mathbf{r}$$

Where σ is the sample electrical conductivity; E is the rms electric field; ρ is the sample density.

The SAR value will depend heavily on the geometry of the part of the body that is exposed to the RF energy, on the exact location and geometry of the radiation source. Thus tests must be on each specific RF source, such as a mobile phone and at the intended position of use. Various governments have defined safety limits for exposure to RF energy produced by mobile devices that primarily exposes the head.

In order to calculate SAR on the time domain FDTD (Finite Difference Time Domain) [10] method is generally used. Here electric field and magnetic field is calculated using Maxwell field equations. For investigation body is divided into large number of small cubic cells. To achieve better accuracy in FDTD simulation, the cell dimensions should be less than one tenth of the wavelength in the medium when it has the highest permittivity.

VI. BIOLOGICAL MODELS FOR MICROWAVE EXPOSURE

It is very difficult to measure the internal E-field strength or temperature elevation in the actual human body using non-invasive methods. So, physical phantom [11] and numerical models [12] are used for the evaluation. In physical phantom method a surrogate of the human body, a so called “phantom” is used. Various types of materials have been developed to build phantom for RF Dosimetry. It is easy to adjust the electrical properties of these phantoms, providing flexibility in RF exposure measurement. Another advantage is easy to scan E-field sensors in these phantoms. While in numerical model the basic characteristics of the RF energy absorption in a human body have been established by simple models such as spheroid. One of the most important recent dosimetric techniques is the development of voxel based anatomical human-body models [13]. A whole-body human voxel model can consist of several million voxels. Various whole-body human models and laboratory animal models have been developed.

VII. INDEPENDENT AND EXPERT REVIEWS

Many expert panels have reviewed the large body of existing scientific literature and have consistently concluded that compliance with the existing science based standards is sufficient to safeguard public health. These reviews have come to resolution that for exposures to radio frequency energy up to levels below the safety limits prescribed by International Commission on Non-Ionizing Radiation Protection (ICNIRP) and sanctioned by WHO, there is no substantive or convincing results that could manifest the biological effects leading to any permanent impairment. Further World Health Organization (WHO) after studying the various research papers presented on the alleged harmful effect of electromagnetic effect on human health has concluded that the current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields [14]. While research continues the WHO has recommended:

- Strict compliance to national or international safety standards.
- Simple protective measures, such as barriers around strong electromagnetic field sources where exposure levels may be exceeded.
- An effective system for public health information and communication among scientists, governments, industry and the public to help raise general awareness of programmes dealing with exposure to electromagnetic fields and reduce any mistrust and fears.

The UK Mobile Telecommunications Health Research (MTHR) program has completed 23 studies, results of which have been published in peer reviewed scientific journals. The report states that none of the research supported by the programme and published so far demonstrates that biological or adverse health effects are produced by radiofrequency exposure from mobile phones [15].

Further, the Committee formed by the Government of India under the Chairmanship of Dr. N.K. Ganguly, Director General, Indian Council on Medical Research which included representatives from PGIMER, Chandigarh & AIIMS New Delhi, has also opined that overall there is not enough evidence to show direct health hazards of RF exposures from Mobile Base Stations. A list of conclusions provided by international organization, proving the exposure of microwaves to be in safe limit has been mentioned in [14]. In additions several independent studies have also been conducted that rejects any association of Mobile phone usage with brain tumor [16].

VIII.CONCLUSION

Since many years, extensive research has been undertaken by researchers of the highest status at various international organizations and general consensus of these studies does not demonstrate any substantive link between human health risks and the use of digital mobile phones. Also, Mobile phones operate at low powers with typical maximum field strengths at ground level which are less than 1% of the international guidelines for public exposures. As the conflicting issue is still alive, it's advisable to reduce the microwave exposure by various techniques as mentioned below:

- Take nutritional supplements, particularly anti-oxidants SOD, catalase, glutathione, Alpha Lipoic Acid and vitamin A, C and E. Various reports suggest that number of antioxidants have an ability to protect from side effects of microwave exposure. Microwave radiation has been shown to decrease levels of these anti-oxidants in the body. These are substances the body produces to protect itself, and their levels are sensitive indicators in stress, aging, infections and various other disease states [17].
- Prefer a phone with a low SAR. Absorbing layers may be applied that reduces the SAR [18]. It has been found that EEG Electrode Caps Can Reduce SAR Induced in the Head by GSM900 Mobile Phones.[19] Further, the total absorbed power for 1800MHz band is lower than for 900MHz band [20].
- Use of cell phone in enclosed spaces such as elevators, where devices may require more power to establish connection, preferably be avoided. Also, avoid making in low coverage zones and keep the call duration to least possible with preference to texting over calling.

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