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Thermal Effects of Radiofrequency Electromagnetic Fields on Human Body

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Abstract: In this study, thermal effects of radiofrequency electromagnetic fields on human body are investigated theoretically. The study will examine waves being in close proximity to the human body, especially the human brain, the conductor for all human body functions. It is to this study we address the answer to the following questions: Is it dangerous to use a mobile? Can electromagnetic radiation from a mobile phone affect my health?

Key words: Electromagnetic energy, thermal effects, thermal effects, ICNIRP, World Health Organization

INTRODUCTION

Electromagnetic Energy (EME) is energy stored in an electromagnetic field, emitted whenever electricity is generated or used. Radiofrequency EME is a subset of EME (covering the frequency range 3 kHz-300GHz). It is also referred to as Radiofrequency EMR or, more often, Radiofrequency Radiation (RFR). EME is emitted from such sources as: power lines, electrical wiring, electrical equipment (eg. radio transmitters, radar and lasers) and electrical appliances (eg. mobile phones, televisions, Visual Display Units (VDUs) and microwave ovens). Mobile phones produce RF radiation that is part of the electromagnetic radiation spectrum. Most mobile phones transmit and receive RF radiation at frequencies of between 800 MHZ and 2.2 GHz (Gezondheidsraad, 1997).

The human body interacts with electromagnetic field present in the environment. Generally speaking, some radiation is being absorbed by the human body when it is exposed to it. For radiofrequencies, the human body interacts with such an electromagnetic field via induced currents and thermal effects, depending on frequencies. The amount by which a body is influenced by electromagnetic fields is determined by the field generated within that body, the so-called internal field.

There has been considerable debate on the health effects of exposure to Radiofrequency (RF) Electromagnetic Radiation (EMR). The increased use of mobile phones has contributed to concerns about the level and effects of radiation emissions. These emit EMR while they are turned on, whether or not a call is being made. Just as some scientific studies have found evidence of adverse effects from mobile phone exposure and others have not, so some people report symptoms after extensive mobile phone use, while others do not. The exposure to EMF can be characterized by several different parameters (field strength, field direction, field orientation in relation to the body exposed, field complexity and so on), though it is not known which of these parameters are associated with risk to human health and the organisms.

The biological and health consequences of these exposure conditions need further understanding. Recommended exposure limits to RFR are set well below levels where any significant heating (thermal effects) could occur. The amount of radiation to which people can be exposed under the standard differs with different technologies. The approximate limits for some common mobile communications technologies are listed in Table 1 (Osepchuk and Petersen, 2003).

The heat generated in the medium is proportional to the absorped power. The biological effects of RF energy depend on the rate at which power is absorbed (Osepchuk and Petersen, 2003). This rate of energy absorption is called the thermal effects (SAR), which is the amount of energy absorbed by a medium per unit of

Table 1: The approximate amount limits for some common mobile communications technologies of radiation to which people can be exposed (Osepchuk and Petersen, 2003)

Technology	Frequency maximum	Exposure
CDMA	800 MHz	400 μW cm^{-2}
GSM	900 MHz	450 μW cm^{-2}
GSM	1800 MHz	900 μW cm^{-2}
3G	2100 MHz	1050 μW cm^{-2}

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volume per unit of time per unit of mass and is expressed in watt per kilogram (W kg^{-1}). SAR is a measure of the rate of radio energy absorption in body tissue and the SAR limit recommended by the International Commission of Non-Ionizing Radiation Protection (ICNIRP) is 2 W kg^{-1} (ICNIRP, 1993). The radiation emitted by mobile phones should be at levels between a SAR of between 0.3 and 2 watts per kilogram. Most phones emit radio signals at SAR levels of between 0.5 and 1 W kg^{-1} (Osepchuk and Petersen, 2003). Specifically, the ICNIRP standard is 0.40 mW cm^{-2} at 800 MHz and 0.90 mW cm^{-2} at 2000 MHz. At mobile phone frequencies it would require a power density of 20-100 mW cm^{-2} to achieve a SAR as high as 4 W kg^{-1} (Gezondheidsraad, 1997), which had been assigned as the maximum permissible level from a health viewpoint (Gezondheidsraad, 1997; Osepchuk and Petersen, 2003; ICNIRP, 1993). At mobile phone frequencies the standard appears to be 0.10 mW cm^{-2}. For situations where exposure is expected to exceed 4 h day^{-1}, the limit appears are further reduced to 0.010 mW cm^{-2}. Local regional administrations appear to have the authority to further reduce these limits and several regions appear to have limits 4 times lower (0.0025 mW cm^{-2}).

Third generation (3G) communications networks perform far more functions that the earlier generations of telecommunications technology. They operate at higher frequencies than their 2G counterparts around 2100 MHz. The present exposure from 3G technology of around 1000 μW cm^{-2}. This is roughly 5 times the level of radiation permitted by the old standard which was 200 μW cm^{-2} (ICNIRP, 1993).

The World Health Organization (WHO) had summarized the results of research studies on the impact of EMF in the laboratory on animals, on humans, at the cellular level and on the biological effects of Extremely Low Frequency (ELF) fields (WHO, 1993b). Evidence for thermal effects of exposure to EMF is identified. Most recent public concern has been with the possible adverse health effects of RFR emitted by digital mobile phone handsets Continuous Radiofrequency (RF) and microwave radiation with intensity less than 10 mW cm^{-2} are unlikely to affect physiology significantly through a thermal mechanisms (Wang and Fujiwara, 1999). However, very little information is available on the non-thermal influences of Electromagnetic Fields (EMFs) caused by these phones on human tissues and more specifically on brain tissues (Hardell *et al*., 1999). While, there is no conclusive proof that a thermal radiation levels from mobile phones cause health problems and not all studies have found effects. Whereas the standard allows public exposures of around 1000 μW cm^{-2}, studies have found problems at much lower levels, such as leukemia (2-8 μW cm^{-2}), cancer (1-2 μW cm^{-2}), memory, attention, endurance (0.0008-0.4 μW cm^{-2}) (Hardell *et al*., 2003, 2002; Freude *et al*., 1998).

A tremendous nubber of investigations (more than 35,000) were conducted to examine diverse health items such as the incidence of brain tumors (Hardell *et al*., 1999, 2003, 2002; Freude *et al*., 1998), influence of electromaencephlogram (Freude *et al*., 1998), excertion of pituitary hormones (De Seze *et al*., 1998), cognitive functions (De Seze *et al*., 1998; Koivisto *et al*., 2000; Preece *et al*., 1999; Wilen *et al*., 2003; Santini *et al*., 2002), thermal changes in the brain (Wilen *et al*., 2003; Santini *et al*., 2002; Cook *et al*., 2002), DNA damage (Wainwright, 2000), lymphocyte and mitogen stimlation (Lai and Sing, 1996), visual functions (Changnaud and Veyret, 1999) etc. The existing scientific evidence does not support the hypothesis that a relation exists between the incidence of brain tumors and the use of GSM-phones. A large number of studies with contradictory results on the influence of mobile phones have been published since 1990.

The goal of this research work is to determine the SAR inside the head of an arbitrary man exposed to RF fields. Heterogeneous head phantoms were assigned for the frequency range from 800-2,450 MHz to determine SAR next to RF sources commonly used in industry and for mobile communication. The investigation will be concerned maily to determine the SAR in tissue are based on computer simulations. Therefore, numerical simulations employing appropriate physical models, with conclusions that are significantly different from those reported in (Anonymous, 2000).

Physical Model and Numerical Simulations: In modeling geometry of the mobile user, one has take into account that such model should preserve the main physical mechanisms responsible for RF energy radiation (from the antenna), coupling (into the accessory wire) and absorption (by the user's body), just as it occurs in practice.

A simple realistic representative model of the human body has been developed previously by Remcom, Inc., (State College, Pennsylvania) (XFDTD, 1994-2001). Such model is based on dividing the human body into small cubic, volume elements, so called 'voxels' (Anonymous, 2000). Each voxel was assigned a tissue type with its associated electromagnetic properties. Meshed in 5 mm resolution voxels and having 23 different tissue types. Simulations processes coverd the frequency range from 100 kHz-10 GHz. The Finite-Difference Time-Domain (FDTD) method was applied for all numerical simulations presented in this study. The dimensions of the grid space for computation was 136×87×397 cubical voxels of 5 mm size.

Currently, exposure guidelines are intended to limit both the total body temperature and the local temperature. They are expressed as 'whole body SAR' and as 'local SAR' averaged over a small mass of tissue. Using some simplifications, the SAR is given by (Osepchuk and Petersen, 2003):

$$SAR = \frac{\sigma|\vec{E}_{int}|^2}{\rho}, \ [W/kg] \quad (1)$$

Where σ is the conductivity of the medium in S/m, ρis the density of the medium in kg m^{-3} and $\vec{E}_{int}$ is the Root-Mean-Squared (RMS) value of the electric field in the medium in V/m. The total SAR (TOTALSAR) is calculated according to Bit-Babik *et al*. (2004)

$$TOTSAR = \iiint_V SAR \ dV = \Delta V \iiint_V \frac{\sigma|\vec{E}_{int}|^2}{\rho} dV, \quad (2)$$

Where ΔV is the volume element enclosed by the stepsize in the x, y and z- directions.

To obtain an impression of the absorption of electromagnetic energy in the body, the SAR is calculated for plane wave incidence. Interaction between EMFs and the human body are attributed to tha fact that the composition of the body differs electromagnetically from its surroundings. Being different from the surroundings is indicated by differences in the permittivity and conductivity. The conductivity of a tissue in fact determines the energy absorption, the power to convert electromagnetic energy into heat. Because, as seen from magnetic viewpoint, man is not very different from his surrpundings, the permittivity of the body is equal to the one of air.

The SAR calculations are performed by a global numerical method caled the three dimensional volume integral equation (Zwamborn and Van de Berg, 1992). Accordingly, the electric field at every place within a certain space can be considered as a homogeneous plane wave. The model of the head is divided into 106×101×80 steps in the x-, y,- and z- directions, respectively. The electric field incide head has been calculated for plane wave incidence. The incident field was taken to be homogeneous and polarized along the y–axis. The SAR is calculated inside each volume element is calculated according to the fast-Fourier-transform method (Zwamborn and Van de Berg, 1994). The tota absorped power of the human head is calculated.

RESULTS AND DISCUSSION

The actual blackbody radiation produced by a human over the frequency range used by mobile telecommunications (0.5-2.4 GHz, 500-2400 MHz) is less than 0.00001 μW cm^{-2}. The above calculation is only correct if you add up all the blackbody radiation produced by the human body below 300 GHz (300,000 MHz). What makes the comparison misleading is that almost all of that blackbody radiation is produced at the upper end of that frequency range (approaching infra-red light), far above the frequencies used by mobile phones. PCS (Personal Communication Systems) phones in the U.S. are hand-held two-way radios that use a digital, rather than the analog transmission system used by older "cell phones". In the U.S., most of the older mobile phones operate at 860-900 MHz, while PCS phones operate at 1800-2200 MHz. In appearance, cellular and PCS phones and their base station antennas are similar. In the U.S., "cordless" phones operate at frequencies ranging from 45-2500? MHz and "Citizens Band (CB)" two-way radios operate at about 27 MHz. Some cordless phones operate at power levels that equal or exceed some mobile phones. The microwave component of the blackbody radiation from the human body is calculated to be around 0.3 μW cm^{-2}. When the average measured emission levels at a distance of 200 m from a 3G base station are compared with human body blackbody emissions, they are about 0.015 μW cm^{-2}, or twenty times less.

The SAR calculations were performed for frequencies range from 800 MHz-2.5 GHz. In this study, the maximum SAR values are averaging over 10 g of body tissue. We used dipole antennas at varying radiated powers. The emitted fields were unmodulated. Measurements were performed in the brain, the inner ears and the eyes of the heads. Evaluations were performed at two antenna positions: Next to the ear (at 20 mm distance to the skull) and at 40 mm in front of the eye.

The specific absorption rate was evaluated by performing measurements of the electric field strength in human tissue and also by measuring the temperature versus time during irradiation of the heads. The evaluation of the absorption rate requires the knowledge of the permittivity of the human tissue. Therefore, permittivity and conductivity were examined in isolated samples of human brain, muscle and eyes before performing the SAR evaluation. The results are given in Table 2 and 3. For instance, the average SAR is calculated over 10 g of tissue and a result of 0.066 mW kg^{-1} was found for a frequency of 2.1 GHz. For 2. 450 Ghz RF energy (power density of 10 mW cm^{-2} and SAR of

Table 2: SAR and total SAR values for RF waves

Frequency (Mhz)	SAR ($W\ kg^{-1}$)	Total SAR ($nW\ kg^{-1}$)	Power density ($mW\ cm^{-2}$)
435	0.32	0.34	1
835	0.75	0.36	0.36
860	1.0	0.47	0.42
900	1.6	0.52	0.45
1500	2.00	0.58	0.63
1600	1.6	0.51	0.7
1800	0.082	0.383	0.9
1900	Up to 10	0.364	0.962
2100 (3G)	0.066	0.328	1.0
2450	1.9	0.315	1.05

Table 3: The maximum SAR in the head phantoms used in the study at an input power of 2 W (McKinlay *et al.*, 2004)

Position	Radiation condition		Max SAR
Brain	Input power 2W, l	433 MHZ	2.00 $W\ kg^{-1}$
Area of right ear	lateral irradiation next	900 MHZ	3.05 $W\ kg^{-1}$
approx.. 1 cm	to the right ear,	1300 MHZ	3.50 $W\ kg^{-1}$
distance to the	feedpoint antenna	1800 MHZ	6.50 $W\ kg^{-1}$
inner side of	2 cm away from	2450 MHZ	6.50 $W\ kg^{-1}$
the skull	surface of head		
Eye	Input power 2W,	900 MHZ	5.57 $W\ kg^{-1}$
In virtreous body	fomtal irradiation	1300 MHZ	7.51$W\ kg^{-1}$
directly behind	of the right eye,	1800 MHZ	5.04 $W\ kg^{-1}$
the lense	feedpoint antenna	2450 MHZ	5.36 $W\ kg^{-1}$
	4 cm away from eye		
Inner ear	Input power 2W,	433 MHZ	0.97 $W\ kg^{-1}$
Area of	lateral irradiation	900 MHZ	1.80 $W\ kg^{-1}$
promontorium	next to the right ear,	1300 MHZ	1.04 $W\ kg^{-1}$
basis of cochlea	feedpoint antenna	1800 MHZ	0.67 $W\ kg^{-1}$
	2 cm away from	2450 MHZ	0.27 $W\ kg^{-1}$
	head surface		

4 $W\ kg^{-1}$ pulsed 435 MHz RF at 1.0 $mW\ cm^{-2}$ (0.32 $W\ kg^{-1}$ plus 2450 MHz RF at 10 $m W\ cm^{-2}$ (10-12 $W\ kg^{-1}$). Futhermore, 929 MHz RF at a SAR of 0.6-0.9 $W\ kg^{-1}$, 1500 MHz RF at a SAR of 2.0 $W\ kg^{-1}$ (McKinlay *et al.*, 2004) Brain SARs ranged from 0.7-1.6 W kg^{-1} and whole-body SAR ranged from 0.2-0.7 $W\ kg^{-1}$; the range of SARs was due to changes in weight and variability in body positioning (Adey *et al.*, 1999).

The minimum SAR for the health effects appears to be in 0.2-1.3 $W\ kg^{-1}$ range, but there are no clear exposure-response relationships at higher SARs. An increase in the SAR values were found around the nose, mouth and forehead. The total SAR is 0.327 $nW\ kg^{-1}$ and 0.316 $nW\ kg^{-1}$ for front and side head calculations.

The radiation used in the study was at SAR levels between 0.3 and 2 $W\ kg^{-1}$. Most phones emit radio signals at SAR levels of between 0.5 and 1 $W\ kg^{-1}$.

As a reference, theoretical calculations in this study had shown that SAR in head tissue of a user of mobile telephone can range from 1.8-7.8 $W\ kg^{-1}$ per watt output of the device. The peak energy output of mobile telephones can range from 0.4-1.2 watt, although the average output could be much smaller. The results are in good agreement with the reported data (Dimbylow, 1997; Dimbylow *et al.*, 1994).

It was found that a SAR of 4 $W\ kg^{-1}$ during a period of 20 min may be resulted in an increasing in the the body temperature of less than 1°C. Normally, the body is generally cope with this increase of temperature, but it is uncertain whether a long term of exposure that might result in a more increase of temperature increases the risk of various effects. In order to avoid this, a safty factor is assigned to the SAR value of 4 $W\ kg^{-1}$. For instance, a safty factor of 10 is assigned for workers and this is resulted in a basis restriction of 0.4 $W\ kg^{-1}$ averaged over the whole body. For the general population, a safty factor of 50 is generally used. This is resulted in a basic restriction of 0.08 $W\ kg^{-1}$ (Gezondheidsraad, 1997).

The weight of evidence available indicates that, for a variety of frequencies and modulations with both short and long exposure times, at exposure levels that do heat the biological sample such that there is a measurable increase in temperature. A transmitted mean power of 0.25 W at 900 MHz was found to increase the skin temperature by 0.25 and 0.12 °C in the brain (Cook *et al.*, 2002). The maximum temperature increase that would occur for a SAR value as large as American standard (1.6- 2 $W\ kg^{-1}$) is about 0.06-0.11 °C at both 900 MHz and 1.5 GHz (Adair, 2003). A temperature increase of 0.9 °C was reported in the presence of non-operational Global System for Mobile Communications (GMS) telephones (Bernardi *et al.*, 2001)greement with (ICNIRP, 1993). A picture of the human head that shoews the head respoonse to EMs is shown in Fig. 1.

However, workers who are exposed to more than ten times the recommended exposure limits of RFR could suffer some adverse health effects. This obviously depends on the duration and severity of the exposure.

Excessive exposure to RFR can give rise to heat exhaustion and could cause irreversible damage to human tissue. It should be noted that workers situated within the vicinity of equipment that generates excessive levels of RFR could also be at risk. It was also found that one hour of exposure to mobile phone radiation caused cultured human cells to shrink. If cells that are "marked" to die do not, tumors can form. The concern about an increased risk of cancer with cellular telephone use is related to the radiation that the device produces. RF radiation can be harmful at high levels because it produces heat. The emitted microwaves heat the metals in the head, such as amalgam fillings braces, crowns bridges, etc. This increases the galvanic electricity generated as well as the emission of mercury vapor that's inhaled from amalgam fillings. Some people have speculated that the heat produced by RF radiation from hand-held cellular telephones may be associated with brain tumors, because the antenna is held close to the user's head.

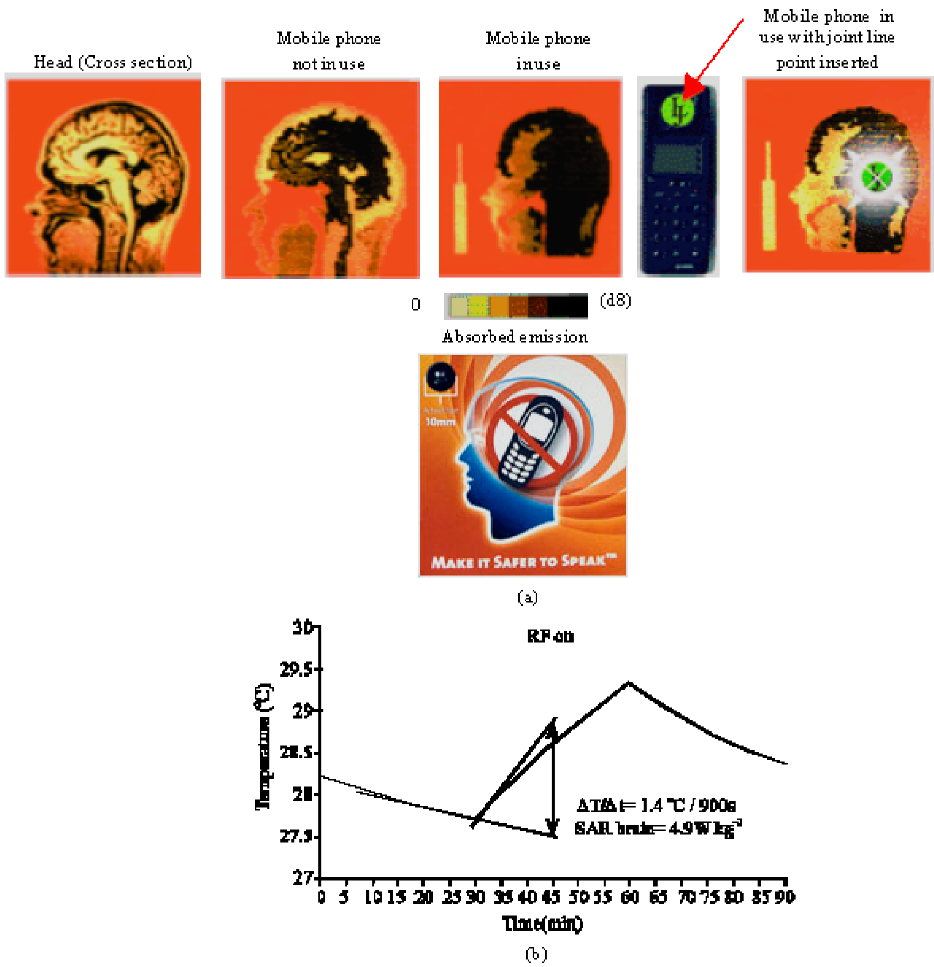

Fig. 1: Electromagnetic emission during use of mobile telephone

There is more and more compelling evidence showing low intensity, pulsed radiation can exert subtle influences that have serious health problems. Your body is an electrochemical instrument of exquisite sensitivity. Its orderly functioning and control are determined by oscillatory electrical processes of various kinds, each characterized by a specific frequency, some of which happen to be close to those used in GSM. Thus, some of your biological electrical activities can be interfered with via oscillatory aspects of the incoming radiation, in much the same way as can the reception on a radio. Your biological electrical activities that are vulnerable to interference from GSM radiation include highly organized electrical activities at a cellular level, whose frequency happens to lie in the microwave region, can interfere with processes as fundamental as cell division. This radiation also seems to affect a variety of brain functions including the neuroendocrine system. Additionally, cell phones have been associated with a 200-300% increase neuroepithelial tumours that occur on the same side of the brain that the cell phone was being used on. People should limit their exposures to these potential dangerous devices that cause irreversible brain damage and cancer. We only have to look less than a hundred years back to learn from similar mistakes our forefathers made in this area.

For 2100 MHz the calculated maximum SAR values of 0.066 mW kg^{-1} after averaging over 10 g of tissue lies well below the reference value of 2 W kg^{-1} asigned bt ICNIRP report (ICNIRP, 1993). Therefore, it is unlikely that any biological efects can be addressed to thermal effects in the head region. From our point of view, the assumption to find no causal relation between the presence of RF fields and the measured parameters is rejected. We have found a statistically significant relation between the field strength and human body.

More research into the effects of RF radiation is being undertaken to answer unresolved questions, there is no convincing evidence that prolonged exposure to very low levels of RF radiation causes any adverse health effects.

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