

Are Mobile Phones Harmful?

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There is increasing public interest in health risks of mobile phone use. Although there is a vast body of material on the biological effects of radiofrequency fields, current risk assessment is still limited. The article describes several hypotheses and results of biological effects such as thermal effect, genetic and carcinogenic effects and cancer related investigations. Mobile phones transmit and receive waves of frequencies mainly at 800–1800 MHz. Findings on the thermal effect of acute exposure to radiofrequency fields were consistent, resulting in an increase of cellular, tissue or body temperature by 1 °C or more. Guidelines for risk limits are based on this thermal effect. Experimental investigation suggests that radiofrequency fields are not tumor initiators and that if they are related to carcinogenicity, this would be by tumor promotion or by increasing the uptake of carcinogens in cells. Implications of these experimental results on public health concerns are yet unclear. Few epidemiological studies are available on the use of mobile phones or on the radiofrequency exposure and the development of cancer. Most of these studies have no or little quantitative exposure data and they are limited by the small number of observations. Large epidemiological studies are necessary in order to investigate the use of mobile phones on the development of cancer. It should be emphasized that even a small elevated risk may have a large implication for public health, as the use of mobile phones and the exposure is rapidly increasing.

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Mobile phones are becoming increasingly popular. It is estimated that some 200 Mio mobile phones are in use worldwide. In countries such as Finland and Italy, nearly 50% of the adult population uses mobile phones and the prevalence is still increasing. Mobile phones operate with radiofrequencies (RF) mainly in the 800 MHz to 1800 MHz range. At sufficiently high intensities, exposure to radiofrequency electromagnetic energy can produce a variety of adverse health effects, such as cataracts of the eye, overloading of the thermo-regulatory response, thermal injury, convulsions and decreased endurance. Therefore, in 1988, the precursor of the future International Non-Ionizing Radiation Committee of the International Radiation Protection Association (ICNIRP) published guidelines on exposure limits to electromagnetic fields in the frequency range from 100 kHz to 300 GHz (1). The guidelines were revised in 1996, when the increasing use of mobile phones became obvious (2). Furthermore, an additional guideline for limiting the exposure to time-varying electric, magnetic, and electromagnetic fields was published in 1998, which in particular took into consideration the growing use of amplitude or pulsed modulated electromagnetic waves and the protection of the general public (3). Since then, there has been a significant increase in the use of hand-held radiotelephones, changing techniques and an

extension of the coverage of reception areas with base transmitters. This has led to concern among users and residents near base stations about the risks to health, including cancer.

TECHNICAL ISSUES

Radiofrequency energy is a component of the electromagnetic energy spectrum, which comprises fields or waves that are characterized by their wavelength, frequency and energy. The total spectrum extends from gamma rays at one end to the electrical and magnetic fields at the other end. Radiofrequency and microwave energy have frequencies in the range 0.1 MHz to 300 GHz. Mobile phones transmit and receive (currently) waves of frequencies mainly at 800–1800 MHz, with some exceptions where waves in the order of 450 MHz are used. This frequency is often modulated by a lower frequency signal. The most common forms of modulation used for telecommunication are frequency or pulse modulation.

In the mid-1980s the first generation of analogue radiotelephones was introduced using frequencies of less than 1 GHz, based on frequency-modulated signals. In the subsequent years different systems have been introduced. Analogue systems are still widespread throughout the world. In Europe the NMT system is mainly used. How-

ever, a gradual replacement by the newer digital system is expected. The digital systems are mostly based on the harmonized European standard (GSM = group spéciale mobile), in which frequencies are allocated so that the analogue system can be transferred to digital systems if needed. Digital mobile telephones are pulse modulated (4).

Mobile phones (hand-held phones, cellular phones) are small transceivers that are normally held against the head during a call. The signals are radiated and received by an antenna. The head of the user is in the near field of the source because the distance from the antenna to the head is a few centimeters. The mobile telephone communicates with base stations. The area where mobile phone use is possible, is subdivided into smaller areas, each being served by a base station. The diameter of these areas differs between a few hundred meters in urban districts up to several kilometers in rural regions. An important feature of the mobile phone technique is the adaptive power control that ensures that the communication can be carried out without unnecessarily high power. This technique complicates the exposure assessment.

For the relevant frequencies (800 MHz–2 GHz) the interaction with biological tissues are related to the rate of energy deposited per unit mass measured in 'specific absorption rate' (SAR) expressed in the unit watt per kilogram (W kg^{-1}). For mobile phone users using a hand-held phone with an antenna, the localized RF exposure is within the head. The power absorption is very inhomogeneous; the SAR values depend on the radiated power, frequency, antenna design, its position to the head and the mode of operation. Basic limits for general public exposure (local SAR of 0.08 W kg^{-1}) are calculated as mean of total body SAR (3). The average SAR values of mobile phone users are below this reference value. However, the local maximum can be significantly exceeded assuming extreme conditions. During the use of mobile phones, an extreme value of 1 to 2 W kg^{-1} in the head can occur, calculated with respect to very small volumes of tissue. This value is close to the SAR limit of 2 W kg^{-1} of head tissue, which is currently recommended (3) and above the guidelines of the Federal Communication Commission in the US, namely 1.6 W kg^{-1} (5).

Base station transmitting antennas are a source of whole-body exposure for people close to them. Approximately, the electric and magnetic field components vary inversely with the distance from the antenna, while the power density varies inversely with the square of the distance. The exposure from base stations is $1/100$ or $1/1000$ smaller than the current limits. Nowadays, quantification of the individual exposure from base stations is impossible because of considerable variations in exposure close to the base stations. The power density is small and is directed only into unspecific areas in the surroundings of the base stations. It has been shown that the distance to a base station is not correlated with the exposure from that

base station. It greatly depends on the location of the station, the direction of the field, and possible shielding through trees and buildings. Living close to a base station may give even lower exposure than living at some distance.

Biological effects

The EMF spectrum varies in its biological effects. While x-rays and gamma rays can break chemical bonds and ionize molecules, RF does not have the capacity to ionize molecules and to produce direct chemical changes in the cells (5). RF can induce electrical currents in cells but these currents are not large in comparison with normal, cellular current flows. From the biophysical point of view, it has been argued that the initial transduction step by which RF can cause harmful effects has not been discovered.

There is a vast body of material on the biologic effects of RF fields, although most data do not relate specifically to hand-held phone use. These data are currently used for risk assessment. However, in order to investigate the effects of prolonged exposure to modulated RF on human health, further investigations are needed, including experiments with a wide range of exposure circumstances and experiments on different biological systems. The current assessment of biological effects is therefore still limited.

Thermal effects

With regard to the thermal effect of acute exposure to radiofrequency fields, the findings were consistent, resulting in an increase of cellular, tissue or body temperature by 1°C or more (this is consistent with an SAR value above 1 – 2 W/kg). Guidelines for risk limits are based on this thermal effect (2).

Genetic and carcinogenic effects

Possible effects on DNA or chromosome structure in somatic cells are considered to be an important indicator, as those changes could be associated with the development of cancer. Many studies of RF-induced genetic effects have been conducted in many different cell and animal systems. Different frequencies were investigated, but published studies including frequencies used in mobile phone techniques are rare, mostly still ongoing. The investigations of the 1970s and 80s on RF-induced genetic changes in microbial test systems invariably gave negative results. In vitro investigations using different cell systems gave negative and positive results but it was argued that the positive results could be attributed to the thermal effects. Because of the many negative findings, it can be concluded that RF fields seem not to induce any genetic damage under non-thermal conditions. Therefore it is unlikely that RF exposure acts as an initiator in the carcinogenicity process. Additionally, most studies did not demonstrate convincingly any direct DNA damage after acute or chronic RF exposure (6).

Cancer-related in vivo investigations

A large number of in vivo investigations in different biological models (different mice and rat strains) have been performed, but mainly on the 2450 MHz waves. Most of these studies do not support the view that even an extensive daily exposure causes tumor growth or tumor proliferation (5). There were only a few positive results indicating that further research is needed in order to understand the process. Szmigielski et al. (7) observed a more rapid development of induced skin tumors in mice exposed over a lifetime to pulsed microwave radiation. Chou et al. (8) conducted a study with rats exposed for a long period to pulse-modulated microwave and found an increase in primary malignant tumors in exposed versus control rats. Repacholi et al. (9) exposed transgenic mice to pulsed digital (GSM-type) radiation and observed an increase in B-cell lymphoma. The implications of these results for human carcinogenicity and concern about public health are yet unclear, but the results beg further research.

Fluxes through cell membranes, gross transcription, cell transformation, or intracellular activity of enzymes such as ornithine decarboxylase were discussed as possible biological effects of exposure to radiofrequency fields (4). Changes in nervous system response were found in rats as well as changes in blood brain barrier permeability (5). Although several hypothetical mechanisms have been proposed to explain the effect of weak electromagnetic fields or electromagnetic radiofrequency fields, there is no generally accepted biophysiological theory that would predict which modulation frequencies do and which do not produce biological effects. Neither do the studies suggest a clear dependency on the exact modulation frequency of the amplitude modulated. The experimental investigation suggests that RF fields are not tumor initiators and that if they are related to carcinogenicity, this would be by tumor promotion or by increasing the uptake of carcinogens in cells.

Cancer-related investigation in humans

In their recent overview, Verschaeve & Maes (6) report on only two studies where genetic effects in human subjects were investigated. In one, an increased incidence of micronucleated white blood cells was found in persons occupationally exposed to RF, but the exposure to other chemicals or environmental factors of the investigated persons were not known. An investigation of radio-line men who were predominately exposed to RF fields gave negative results.

EPIDEMIOLOGIC STUDIES

Only some health effects of mobile phones are well documented: The use of cellular telephones is associated with a higher risk of a collision during the brief period of a call, which in most countries led to a banning of the use of

mobile phones while driving a car (10); certainly this is not related to RF exposure. Furthermore, it is recognized that, under certain circumstances, radiofrequency emissions from hand-held radiotelephones can cause interference with the function of some electrical and electronic equipment such as pacemakers, insulin pumps or equipment in hospital intensive care departments (11–13).

Few epidemiological studies are available on the use of mobile phones or on RF exposure and the development of cancer. Some information can be found in studies of persons exposed to radar or radio-broadcasting exposure. Those studies have been recently reviewed with respect to the risk of leukemia, breast cancer and brain tumors (14). A major problem is that in most of these studies no or very little quantitative exposure data are available and no data on specific frequencies of electromagnetic fields were used for the analysis. In general, the relative risks that have been found for the association between high-frequency fields and cancer are small. The results, particularly for leukemia, were inconsistent, while the association with brain tumor shows more regular results, although the numbers are small and the quality of some studies is debatable. Very few studies have been published evaluating the risk of breast cancer after RF exposure (14).

As mobile phones have been used only for a relatively short period, epidemiological studies on the health effects are rare and report only short-term results. A record-based mortality surveillance of more than 250000 mobile phone clients was started in 1994 to investigate health effects related to the use of different types of cellular phones. The age-adjusted mortality rate for users of portable phones was similar to that for mobile telephone users (15). Additional analyses of cause-specific mortality were limited by the short follow-up time. With respect to specific cancer-related mortality, no conclusions could be drawn. Nevertheless, car collision mortality was inversely associated with numbers of calls per day (16). Recently, a Swedish case control study including 233 brain tumor cases and 425 controls was published. Overall, no increased risk for brain tumors has been found in association with exposure to the analogue or digital systems of mobile telephones. A non-significant increased risk for temporal or occipital brain tumors was found for persons who had used their mobile phones on the same side of the head, based on 13 cases only. The increase in risk was restricted to those that used NMT but not confirmed in GSM users (17). Currently, two case control studies of brain tumors in the United States and one cohort study on mobile phone users in Denmark are being carried out; the results of these studies are expected soon.

International epidemiological studies are necessary in order to investigate the influence of high-frequency radiation and amplitude-modulated radiofrequency radiation on the development of cancer. Several workshops have been held in recent years under the International Electro-

magnetic Field Project and other organizations to identify any health hazards from RF exposure and to identify gaps in the knowledge requiring further research. These workshops have been sponsored or initiated by ICNIRP, WHO, national governments and research institutions. In most of these workshops it was concluded that, although hazards associated with exposure to high-level (thermal) RF fields have been found, there are no known health effects associated with exposure to sources that emit RF fields. The power is too low to cause a significant temperature rise in the tissues. However, as some inconsistent results have been reported, further research is warranted. In vivo studies should focus on the RF potential for tumor promotion, co-promotion and progression, as well as possible synergistic, genotoxic, immunological and carcinogenic effects. Epidemiological studies should investigate the use of mobile phones and incidence of various cancers, mainly of the brain and leukemia. Case-control studies comprising a large number of cases are needed in order to have sufficient sample sizes to detect small, increased risks. The International Agency for Cancer (IARC) is currently launching a multinational case control study of brain tumor cancer. The study will be carried out in 13 countries and will include some 6000 brain tumors. In addition, cohort studies of mobile phone users should be carried out to observe incidence or mortality of cancer and other chronic diseases in exposed populations. It should be emphasized that even a small elevation in risk may have wide implications for public health, as the use of mobile phones and the exposure are likely to increase rapidly in the next few years.

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