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Health risks from the use of mobile phones

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Abstract

Widespread concerns have been raised about the possibility that exposure to the radiofrequency (RF) fields from mobile telephones or their base stations could affect people's health. Such has been the rapid growth of mobile telecommunications that there will be about one billion mobile phone users before 2005. Already there are more mobile than fixed-line users. Developing countries are establishing mobile telecommunications rather than the more expensive fixed-line systems. Thus, if there is any impact on health from mobile telephones, it will affect everyone in the world. The World Health Organization (WHO) established the International EMF Project in 1996 to evaluate the science, recommend research to fill any gaps in knowledge and to conduct formal health risk assessments of RF exposure once recommended research had been completed. In addition, the UK government established an independent expert group to review all the issues concerning health effects of mobile telephones and siting of base stations. Cancer has been suggested as an outcome of exposure to mobile telephones by some scientific reports. This paper reviews the status of the science and WHO's programme to address the key issues. In addition, the main conclusions and recommendations of the UK expert group will be summarised.

Keywords: Mobile phones; Health effects; Radiofrequency fields; Cancer

1. Introduction

Concern continues about exposure to radiofrequency (RF) fields from sources used for mobile telecommunications, radars, radio and television broadcast, medical and industrial applications. Much of this concern arises because new technologies are introduced without provision of public information about their nature or discussion of the debate within the scientific community about possible health consequences. In the meantime, mobile phone use has increased dramatically with falling costs. Industry sources suggest that there will be over one billion users worldwide by 2005, far exceeding telephone use via fixed-lines.

Of particular concern to the World Health Organization (WHO) is the fact that, if any adverse health effect is established from mobile phone use, it will be a global concern because developing countries are establishing this technology in preference to the more-expensive fixed line systems. Thus, even a small impact on health could have a major public health consequence.

The output power from the antennas of digital mobile telephones is much lower than the earlier

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technology analogue models. However, RF emissions from the base stations that communicate between the mobile phones and the networks are orders of magnitude smaller than from handsets. Yet the key concern of the public has been the apparently ad hoc erection of base stations in their living environment without adequate consultation. To compound the problem, the media sees electromagnetic fields (EMF) as a newsworthy issue so that newly published scientific research is sensationally reported without qualification from the results of previous studies.

To address these concerns, WHO established the International EMF Project in 1996 and is collaborating with eight international organizations, seven WHO collaborating institutions and over 45 national authorities. The International EMF Project, in collaboration with the International Commission on Non-Ionizing Radiation Protection (ICNIRP), has completed initial international scientific reviews of possible health effects of exposure to EMF. These reviews provide interim conclusions on health hazards from exposure to EMF and gaps in knowledge requiring further research before better health risk assessments could be made by WHO. Results of the RF review covering the frequency range 10 MHz to 300 GHz have been published (Repacholi, 1998). An updated review was completed in late 1999 and the results will be published in early 2001.

Sufficient concern was voiced in the UK that the Minister for Public Health established an Independent Expert Group on Mobile Phones (IEGMP) 'To consider present concerns about the possible health effects from the use of mobile phones, base stations and transmitters, to conduct a rigorous assessment of existing research and to give advice based on the present state of knowledge. To make recommendations on further work that should be carried out to improve the basis for sound advice.' This group has now published its report (IEGMP, 2000) and the results are available on its web site: http://www.iegmp.org.uk.

This paper summarises the results of the WHO and IEGMP reviews with respect to health consequences from mobile phone use, research needed to evaluate properly possible health effects required to make better health risk assessments, and what WHO will be doing to resolve this issue. Finally, a summary of WHO recommendations is given on what can be done while research is completed and evaluated.

2. WHO requirements for evaluating health risks

Unfortunately, there have been many published RF studies that have either been of insufficient quality to contribute to health risk assessments, or they have been unconfirmed but raise potentially serious health questions and so need confirmation. To address the former, WHO has published its requirements for quality research, what research is still needed to assess health risks and how health risks are evaluated. These are summarised in the following.

2.1. Quality research

For new studies to be useful to future health risk assessments, the research must be of high scientific quality with clearly-defined hypotheses, estimates should be given of the ability of the study to detect small effects, and protocols that are consistent with good scientific practice should be used. Quality assurance procedures should be included in the protocol and monitored during the study.

2.2. Biological effects and health hazards

The WHO constitution defines health as a state of complete physical, mental and social well being, and not merely the absence of disease or infirmity. This definition includes an important subjective component that must be taken into account in health risk assessments. Within the International EMF Project, a working definition of health hazard has been developed: A health hazard is a biological effect outside the normal range of physiological compensation that is detrimental to health or well being. In this definition, a biological effect is a physiological response to exposure. For the biological effect to lead to some adverse health consequence, it should be outside

the normal range of compensation, in order to place it beyond normal variation in body responses.

2.3. Determining research needs

Criteria used to evaluate health risks by the International EMF Project were adapted from those used by WHO's International Agency for Research on Cancer (IARC) (Repacholi and Cardis, 1997). Thus, to determine research requirements, it was first necessary to assess what the composition of a database of research results should include for IARC and WHO to assess health risks comprehensively. Research needs were also identified when published evidence for a health risk was judged suggestive, but insufficient to meet the criteria for assessing health risk. Research needs were also established on the basis of unconfirmed effects having implications for health, and replication of key studies to confirm effects. Thus, the overall goal is to promote studies that demonstrate a reproducible effect of EMF exposure that has the likelihood to occur in humans and has a potential health consequence.

While in vitro studies can provide important insights into fundamental mechanisms for biological effects from exposure to low-level EMF, in vivo studies, whether on animals or human beings, provide more convincing evidence of adverse health consequences. Epidemiological studies provide the most direct information on risks of adverse effects in human beings. However, these studies have limitations, especially when low relative risks are found. Epidemiological studies are important for monitoring public health impact of exposure, particularly from new technologies.

Priority should be given to studies designed to investigate health hazards of:

- concern to the general public;
- potential public health importance (based on the size of the populations potentially exposed, the extent of their exposure, and the seriousness of the hypothesised adverse effect);
- scientific importance (e.g. testing the relevance of effects observed or mechanisms postulated on the basis of in vitro or in vivo results).

3. Mechanisms of interaction

RF fields induce torques on molecules that can result in displacement of ions from unperturbed positions, vibrations in bound charges (both electrons and ions), and rotation and reorientation of dipolar molecules such as water. These mechanisms, which can be described by classical electrodynamic theory, are not capable of producing observable effects from exposure to low-level RF fields, because they are overwhelmed by random thermal agitation. Moreover, the response time of the system must be fast enough to allow it to act within the time period of the interaction. Both considerations imply that there should be a threshold (below which no observable response occurs) and a cut-off frequency (above which no response is observed). These thresholds would be expected to be present even in more refined models if they correctly take into account thermal noise and the kinetics of the system.

Exposure to EMF at frequencies above about 100 kHz can lead to significant absorption of energy and temperature increases. In general, exposure to uniform (plane-wave) EMF results in a highly non-uniform deposition and distribution of energy within the body, which must be assessed by dosimetric measurement and calculation. For absorption of energy by the human body, EMF can be divided into four ranges:

- about 100 kHz to less than about 20 MHz, where absorption in the trunk decreases rapidly with decreasing frequency, and significant absorption may occur in the neck and legs;
- from about 20 MHz to 300 MHz, at which relatively high absorption can occur in the whole body, and to even higher values if partial body (e.g. head) resonances are considered;
- from about 300 MHz to several GHz, at which significant local, non-uniform absorption occurs;
- above about 10 GHz, at which energy absorption occurs primarily at the body surface.

In tissue, the specific absorption rate (SAR) of RF energy absorbed per unit mass is proportional

to the square of the internal electric field strength. The average SAR and SAR distribution can be computed or estimated from laboratory measurements. Values of SAR depend on the following factors.

- The incident field parameters, i.e. the frequency, intensity, polarization, and source–object configuration (near field or far field).
- The characteristics of the exposed body, i.e. its size, internal and external geometry, and the dielectric properties of the various tissues.
- Reflection, absorption and scattering effects associated with the ground or other objects in the field near the exposed body.

When the long axis of the human body is parallel to the electric field vector, and under plane-wave exposure conditions (i.e. far-field exposure), whole-body SAR reaches maximal values. The amount of energy absorbed depends on a number of factors, including the size of the exposed body. 'Standard Reference Man', if not grounded, has a resonant absorption frequency close to 70 MHz. For taller individuals the resonant absorption frequency is somewhat lower, and for shorter adults, children, babies, and seated individuals it may exceed 100 MHz. The values of electric field exposure limits are based on the frequency dependence of human absorption. In grounded individuals, resonant frequencies are lower by a factor of about 2 (ICNIRP, 1998).

This description of RF absorption applies to whole-body exposure from distant sources such as base stations. However, mobile phone antennas give localised RF exposures predominantly to the head. Thus, it is necessary to determine the local SAR and its distribution in the head to properly evaluate health consequences. Calculation of the maximum temperature rise in the head from RF exposure during mobile telephone use suggests that increases of no more than about 0.1°C would be expected (Van Leeuwen et al., 1999). Thus if there are health effects from low-level RF exposure, they are unlikely to be due to any temperature increase. So-called non-thermal mechanisms of RF action in tissues have been proposed, but none have received experimental support.

4. Biological effects of exposure to RF fields

The following summarises the results and conclusions of the WHO (Repacholi, 1998) and IEGMP (2000) reviews, as well as more recent results, with emphasis on the possibility that RF exposure could result in cancer.

There is little information about possible health effects from localised RF exposures or about the effects of different pulsing regimens that RF fields are used in mobile telecommunications; this is where there are gaps in knowledge. A summary of the results of studies investigating effects of RF exposure on living systems is given in the following.

4.1. In vitro studies

Reports from in vitro research indicate that low-level RF fields may alter membrane structural and functional properties that trigger cellular responses. It has been hypothesised that the cell membrane may be susceptible to low-level RF fields, especially when these fields are amplitude modulated at low frequencies. At high frequencies, however, low-level RF fields do not induce appreciable membrane potentials. They can penetrate the cell membrane and possibly influence cytoplasmic structure and function. These RF field-induced alterations, if they occur, could be anticipated to cause a wide variety of physiological changes in living cells that are only poorly understood at the present time (Repacholi, 1998).

A lack of effects of RF exposure on mutation frequency has been reported in a number of test samples including yeast and mouse lymphoid cells. No effect of RF-field exposure on chromosome aberration frequency in human cells has been confirmed (IEGMP, 2000).

4.2. In vivo studies

In contrast to the evidence already given, several studies indicate that RF fields may affect DNA directly. These papers (Lai and Singh, 1995, 1996) report quantitative data subject to sources of inter-trial variation and experimental error such as incomplete DNA digestion or unusually

high levels of background DNA fragmentation (IEGMP, 2000). These experiments have not been replicated (Malayapa et al., 1997a,b, 1998). Furthermore, most well conducted investigations report a lack of clastogenic effect in the somatic or germ cells of exposed animals (ICNIRP, 1998). Other investigations that require further attention relate to possible synergistic action of RF exposures with chemical or physical mutagens or carcinogens.

Most cancer studies of animals have sought evidence of changes in spontaneous or natural cancer rates, enhancement by known carcinogens, or alterations in growth of implanted tumours (IEGMP, 2000). However, they have provided only equivocal evidence for changes in tumour incidence. Chronic RF field exposure of mice at 2–8 W/kg resulted in an SAR-dependent increase in the progression or development of spontaneous mammary or chemically induced skin tumours. In a further study, exposure at 4–5 W/kg, followed by application of a sub-carcinogenic dose of a chemical carcinogen to the skin, a procedure repeated daily, eventually resulted in a threefold increase in skin tumours (Szmigielski et al., 1982, 1988; Szudzinski et al., 1982). However, at these high exposures, temperature-mediated effects cannot be excluded.

Studies in which cancer cells were injected into animals have reported a lack of effect from exposure to continuous wave (CW) and pulsed RF fields on tumour progression. Progression of melanoma in mice was unaffected by daily exposure to pulsed or CW RF fields following subcutaneous implantation, and progression of brain tumours in rats was not affected by CW or pulsed RF fields following the injection of tumour cells into the brain.

Moderately lymphoma-prone Eμ-*Pim1* oncogene-transgenic mice were exposed or sham-exposed to radiofrequency fields for 1 h/day for up to 18 months using pulse modulations similar to that used for digital mobile telephones. Exposure was associated with a statistically significant 2.4-fold increase in the risk of developing lymphoma (Repacholi et al., 1997). This long-term study needs replication and extension to other exposure levels and animal models before it can be used for health-risk assessments. Further research is also needed to determine the significance of effects in this transgenic model for human health risk.

In their review of cancer studies, the IEGMP (2000) concluded that: some individual experimental studies have suggested that RF radiation can initiate tumour formation, enhance the effects of known carcinogens or promote the growth of transplanted tumours. However, in some of these, the intensity was high enough to produce thermal effects. The balance of evidence, from both in vitro and in vivo experiments, indicates that neither acute nor chronic exposure to RF fields increases mutation or chromosomal aberration frequencies when temperatures are maintained within physiological limits (UNEP/WHO/IRPA, 1993). This suggests that RF exposure is unlikely to act as a tumour initiator. Furthermore, a variety of cancer studies using animals have sought evidence of an effect of RF exposure on spontaneous or natural cancer rates, the enhancement of the effects of known carcinogens or effects on the growth of implanted tumours. However, they have provided equivocal evidence for an effect on tumour incidence (ICNIRP, 1998; Moulder et al., 1999; Repacholi, 1998; Royal Society of Canada, 1999).

5. Behaviour

Early signs of neurotoxicity are often behavioural rather than anatomical (Salzinger, 1994). The behaviour of animals can be a very sensitive indicator of adverse health consequences and can be used to investigate the biological basis of memory, and studies with non-human primates can serve as a model of human cognitive functions. Early studies were conducted using whole-body exposure to high RF levels or low average levels using high peak-power pulses. These studies produced behavioural changes that were considered to have potential health consequences at the lowest RF exposures and form the basis for international guidelines limiting human exposure to RF.

Effects on behaviour have been obtained at exposure levels well above guideline limits, but

some studies have reported effects on behaviour at levels below these limits. Also, few relevant experiments have used low-level fields with characteristics similar to those used in telecommunications systems (UNEP/WHO/IRPA, 1993; Repacholi, 1998; Royal Society of Canada, 1999). Replication and confirmation studies are needed to provide further information on these effects.

In the most recent review of behavioural effects (IEGMP, 2000), this committee concluded that: "Increases in core temperature of 1°C or more certainly lead to changes in the performance of well-learned tasks and other simple behaviours. However, there is no consistent experimental evidence that exposure to low level RF fields affects learning and memory in animals. The studies of Lai and co-workers challenge these conclusions and suggest that spatial learning can be disturbed at average SARs below 1 W/kg. However the peak-pulse energy was much higher than that associated with mobile phones, the effects reported were statistically weak and they have not been reproduced by Sienkiewicz et al. (2000) using 900 MHz fields. D'Andrea (1999) has speculated that some cognitive tasks may show particular sensitivity to RF exposure, and effects on these behaviours may occur at SARs below those required to disrupt simple, well-learned tasks."

6. Pulsed radiation studies

Exposure to very intense pulsed RF fields suppresses the startle response and evokes body movements in conscious mice (ICNIRP, 1998). The mechanism for these effects is not well established, and is clearly associated with heating at higher absorbed energies.

People having normal hearing perceive pulse-modulated RF fields with carrier frequencies between about 200 MHz and 6.5 GHz; the so-called microwave hearing effect (Chou et al., 1985). The sound has been variously described as a buzzing, clicking, hissing or popping sound, depending on modulation characteristics. Prolonged or repeated exposure may be stressful.

The retina, iris and corneal endothelium of the primate eye were reported to be susceptible to low-level RF fields, particularly when pulsed. Various degenerative changes in light sensitive cells in the retina were reported at specific energies per pulse (10 μs pulses at 100 p.p.s.), as low as 2.6 mJ/kg after the application of a drug used in glaucoma treatment. However, these results could not be replicated for CW fields. Further replication studies are needed.

7. Epidemiological and human volunteer studies

7.1. Cancer

By far the greatest public concern has been that exposure to low-level RF fields may cause cancer. Of the epidemiological studies addressing possible links between RF exposure and excess risk of cancer, some positive findings were reported for leukaemia and brain tumours. Overall, the results are inconclusive and do not support the hypothesis that exposure to RF fields causes or influences cancer.

Review groups evaluating possible links between RF exposure and excess risk of cancer have concluded that there is no consistent evidence of a carcinogenic hazard. In some studies, there are significant difficulties in assessing disease incidence with respect to RF exposure and with potential confounding factors such as extremely low frequency and chemical exposure. Overall, the epidemiological studies suffer from inadequate assessment of exposure and confounding, and poor methodology. Further studies are underway to evaluate potential carcinogenic effects of chronic exposure to low-level RF fields and more are needed.

From their review of epidemiological studies related to cancer outcomes, IEGMP (2000) concluded: the epidemiological evidence currently available does not suggest that RF exposure causes cancer. This conclusion is compatible with the balance of biological evidence, which suggests that RF fields below guidelines do not cause mutation, or initiate or promote tumour formation. However, mobile phones have not been in use for long enough to allow comprehensive epidemiological assessment of their impact on health,

and we cannot, at this stage, exclude the possibility of some association between mobile phone technology and cancer. In view of widespread concern about this issue, continued research is essential.

7.2. Other health outcomes

Other health outcomes investigated following RF exposure include headaches, general malaise, short-term memory loss, nausea, changes in electroencephalography and other central nervous system functions, and sleep disturbances. There have been anecdotal reports from several countries of subjective disorders such as headaches associated with the use of mobile telephones. Whether exposure to RF fields at very low-levels can cause such subjective effects has not been substantiated from current evidence, but further research is indicated (Repacholi, 1998).

Individuals have claimed to be hypersensitive to EMF. The most common symptoms are headaches, insomnia, tingling and rashes of the skin, difficulty in concentrating and dizziness. Given the limited evidence and widespread concerns that the presented effects have provoked, more research is needed to determine whether these health effects can be substantiated. Current evidence suggests that these symptoms are psychosomatic and unrelated to EMF exposure (Bergqvist and Vogel, 1997; COST 244bis, 1998).

Adverse maternal health outcomes, particularly spontaneous abortions and haematological or chromosome changes, have been reported to occur in certain populations exposed to RF fields. Some of these changes have also been reported in users of video display units. Taken overall, the studies in this area have not substantiated these effects (Repacholi, 1998).

8. Research needs

Through the international review process where scientists from every discipline were invited to discuss gaps in knowledge, WHO has formulated its research requirements. Once this research is complete, the results will form a database that can be used to conduct better health risk assessments. In summary, the research needs are as follows.

RF research should concentrate on mobile telephones, working populations exposed to high levels of RF, and emerging technologies that use RF fields. There is a great need for very well-conducted epidemiological studies of mobile telephone users. One such study will be conducted by the WHO specialized agency for cancer research, the International Agency for Research on Cancer (IARC). This study will be conducted simultaneously in at least ten countries and determine if mobile telephone use is associated with an increase in head and neck cancers. Other similar epidemiological studies are underway to provide much needed information in the area of research.

Animal studies are needed where animals are exposed to RF fields simulating human exposure situations. Of primary importance is to determine whether RF fields can initiate, promote or progress cancer. Many studies are currently underway that address the cancer issue.

In addition to animal studies, it is possible to test human reactions to RF exposure in controlled laboratory studies. Here, healthy individuals are exposed to RF fields to determine whether they are sensitive to these fields, suffer headaches or other subjective symptoms, or suffer changes in blood pressure, heart rate, or memory loss. All these effects are considered adverse and need to be characterised and addressed in proper studies that further our knowledge in this area.

Studies are also conducted on cells, either in a nutrient solution or as pieces of tissue. These are very important for determining exactly how RF fields interact with living tissues. However, even if an effect of RF exposure is found in these cells, it does not necessarily mean that the same effect will occur in whole animals or humans. Once an effect is found, it still needs to be studied further to determine if it has any adverse effect in humans.

More details on RF research needs have been described in WHO's EMF research agenda (WHO, 1998) and is also available on the WHO web site: www.who.int/emf.

9. Current WHO recommendation on mobile phones and their base stations

A WHO fact sheet updating conclusions and recommendations regarding health effects from mobile phone use and exposure to base stations was published in June 2000 (WHO, 2000). It states that: none of the recent reviews have concluded that exposure to the RF fields from mobile phones or their base stations causes any adverse health consequence. However, there are gaps in knowledge that have been identified for further research to better assess health risks. It will take about 3–4 years for the required RF research to be completed, evaluated and to publish the final results of any health risks. In the meantime, WHO recommends the following.

- Strict adherence to health-based guidelines. International guidelines have been developed to protect everyone in the population: mobile phone users, those who work near or live around base stations, as well as people who do not use mobile phones.
- Precautionary measures

  Government. If regulatory authorities have adopted health-based guidelines but, because of public concerns, would like to introduce additional precautionary measures to reduce exposure to RF fields, they should not undermine the science base of the guidelines by incorporating arbitrary additional safety factors into the exposure limits. Precautionary measures should be introduced as a separate policy that encourages, through voluntary means, the reduction of RF fields by equipment manufacturers and the public. Details of such measures are given in a separate fact sheet.

  Individuals. Present scientific information does not indicate the need for any special precautions for use of mobile phones. If individuals are concerned, they might choose to limit their own or their childrens' RF exposure by limiting the length of calls, or using 'hands-free' devices to keep mobile phones away from the head and body.
- Obey local restrictions on mobile phone use to avoid EMF interference. Mobile phones may interfere with certain electromedical devices, such as cardiac pacemakers and hearing aids. In hospital intensive care departments, mobile phone use can be a danger to patients and should not be used in these areas. Similarly, mobile phones should not be used in aircraft as they may interfere with its navigation systems.
- Driving safety. In moving vehicles, there is a well established increase in the risk of traffic accidents while the driver is using a mobile phone, either a conventional handset or one fitted with a 'hands free' device. Motorists should be strongly discouraged from using mobile phones while driving.
- Simple protective measures. Fences or barriers or other protective measures are needed for some base stations (principally, those located on building rooftops) to preclude unauthorised access to areas where exposure limits may be exceeded.
- RF absorbing devices. Scientific evidence does not indicate any need for RF-absorbing covers or other 'absorbing devices' on mobile phones. They cannot be justified on health grounds and the effectiveness of many such devices in reducing RF exposure is unproven.
- Consultations with the community in siting base stations. Base station sites must offer good signal coverage and be accessible for maintenance. While RF field levels around base stations are not considered a health risk, siting decisions should take into account aesthetics and public sensibilities. Siting base stations near kindergartens, schools and playgrounds may need special consideration. Open communication and discussion between the mobile phone operator, local council and the public during the planning stages for a new antenna can help create public understanding and greater acceptance of a new facility.
- Providing information. An effective system of health information and communications among scientists, governments, industry and the public is needed to raise the level of general understanding about mobile phone technology and reduce any mistrust and fears, both real and perceived. This information should be accurate, and at the same time be appropriate in

its level of discussion and understandable to the intended audience.

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