Electromagnetic radiation

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Electromagnetic fields (EMF) are ubiquitous in modern society. It is well known that exposure to strong fields can result in acute effects, such as burns; the mechanisms behind such effects are well established. There is, however, also a concern that long-term exposure to weak fields might have health effects due to an as-yet unknown mechanism. Because of the already widespread exposure, even small health effects could have profound public health implications. Comprehensive research efforts are therefore warranted, and are indeed ongoing. The strongest evidence for health risks is from exposure to fields generated in connection with use of electric power. As for fields used by telecommunications technology, there is still considerably fewer data available and for the time being there is only very weak support for the existence of health effects. However, extensive research activities are ongoing and much more data will be available in the near future. This situation of scientific uncertainty and considerable public concern creates dilemmas for decision makers.

Introduction

Electromagnetic fields are ubiquitous in modern society. They occur in connection with use of electric power, electronic surveillance systems and various types of wireless communications. While these fields differ with respect to strengths and physical characteristics, they all give rise to concern among those exposed about the possibility of health risks. It is well established that strong fields can give rise to acute health effects, such as burns, but exposure guidelines and regulations protect effectively against such effects. Current concerns are instead directed towards the possibility that long-term exposure to weak fields might have detrimental health effects due to some, to date unknown, biological mechanism.

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Due to the widespread use of these techniques and the very prevalent exposure to some of the types of field involved, even a weak association with disease risk could have strong impacts on public health. Although the likelihood of such a scenario is debatable, it is the opinion of many that close monitoring of health risks among exposed subjects is a high

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priority. Indeed, extensive research is ongoing and has been so for several years. A report linking childhood cancer mortality to the presence of power lines in the near proximity to the children's homes about 25 years ago spurred the interest in power frequency fields[1]. This interest has remained high ever since, although it has gradually shifted towards other types of field, and in particular towards those used in connection with telecommunications.

The objective of this paper is to discuss the evidence pertaining to the possibility that long-term exposure to weak fields of the types discussed above may be associated with health risks.

The electromagnetic spectrum and low frequency fields

The electromagnetic spectrum encompasses a wide variety of electromagnetic fields, including static fields, radio frequency fields, UV radiation, visible light and X-ray radiation. Electromagnetic fields are characterized by their frequency or wavelength; the wavelength is inversely proportional to the frequency. At the lower end of the electromagnetic spectrum, it is customary to refer to the frequency, while at the upper end one usually uses wavelength. The radiation energy is directly proportional to the frequency, as described by Planck's law. The electromagnetic spectrum can be divided into an ionizing and a non-ionizing segment. In the non-ionizing part, the radiation energy is too weak to break chemical bonds and, thus, to form ions. In contrast, ionizing radiation carries enough energy to break chemical bonds. The border between non-ionizing and ionizing radiation is located roughly at the upper end of the UV-band. This paper deals with potential health risks from a subset of the non-ionizing part of the spectrum, namely fields of frequencies up to 300 GHz; these fields are often called low frequency fields.

This frequency band includes fields that are generated in connection with production, transmission, distribution and use of electric power. Such fields usually have a frequency of 50 or 60 Hz. We will refer to these frequencies as ELF (extremely low frequency). The low frequency band also includes fields that are used for communication with mobile telephony. This technology typically uses frequencies from 450 up 2500 MHz, although new technology will extend this band upwards. We refer to this as RF (radiofrequency). Use of electricity and telecommunications are the technologies that have caused most of the current concern regarding possible health risks and for which most research is available. However, quite a number of other applications also employ fields in the range below 300 GHz. Television and radio transmitters use frequencies similar to mobile phones, as do microwave ovens. Surveillances system of the type found in stores, as well as by cashier machines, often use so-called intermediate frequencies, up to about 40 kHz. Static fields are used for example by magnetic resonance imaging (MRI).

ELF magnetic fields in the environment are usually characterized by their flux density, which is measured in units of Tesla (T) or microTesla (μT). Environmental RF fields are characterized by their power density, measured as Watt per square metre (W/m^2).

Established mechanisms of interaction

The ELF fields have a long wavelength; indeed 50 Hz corresponds to a wavelength of 3500 km, which is similar to the Earth's radius. As a consequence, such fields essentially pass through the body without depositing any energy. The established mechanism of interaction between such fields and the human body is induction of electric currents. The current density induced in the body is a direct consequence of the external magnetic field flux density; this is the reason why such fields are typically characterized by their μT-level. It is well established in laboratory studies and in theoretical calculations that high internal current densities cause acute biological effects. The biophysical quantity that is used to characterize the induced currents is Ampere per square meter. Existing exposure guidelines are expressed in terms of so-called basic restrictions and primarily aim to prevent neurological effects by restricting the internal current density[2]. The environmental flux densities required to produce internal current densities that exceed the basic restrictions are orders of magnitude above what one normally encounters in the general environment. The exception is certain work places where high electric fields can momentarily result in current densities near the guideline reference values.

The RF fields have wavelengths in the order of a few centimetres or less, depending on the actual frequency. Depending on the field strength, some energy is deposited in the body, mainly within one or two centimetres of its surface. The only known consequence of this is heating. The purpose of the basic restrictions in existing guidelines is to prevent excessive heating, locally or in the whole body[2]. The physical quantity that is used in this context is the specific absorption rate (SAR), measured in W/kg. The internal SAR cannot be measured directly inside the body, but is established based on models and theoretical calculations. The SAR values that are indicated on some mobile phones are derived in this way and reflect the maximum SAR value that a particular phone is assumed to be able to produce. The actual field levels that people encounter in connection with mobile phone use produce SAR values below the basic restrictions, although of the same order of magnitude. The fields from base stations that people experience, on the other hand, are much weaker; they are in fact several orders of magnitude below the guideline levels.

Potential health risks from weak long-term exposure: ELF

Given the small amount of energy that is deposited in connection with exposure to ELF fields, any health effects due to weak long-term exposure would have to be produced by a to-date unknown biophysical mechanism. Despite this, researchers have been intrigued by this possibility. Ahlbom *et al*[3] give a comprehensive overview of the relevant epidemiology. The interest originates to no small extent from the early epidemiological study by Wertheimer and Leeper[1]. The results from this suggested that childhood cancer mortality was associated with the existence of power lines near the children's homes, and particularly with such power lines that were indicative of high magnetic field exposure. Although the implications by many were considered implausible, and despite several methodological problems in the study, that work has been followed by several attempts to replicate the findings. To date, close to 20 studies on childhood cancer and residential exposure to ELF fields have been published[3]. The studies have generally been of increasing methodological strengths, particularly with respect to assessment of magnetic field exposure but also with respect to selection bias and other methodological aspects. The first few of these replications addressed a variety of cancer types and also total cancer, but later studies have increasingly focused on childhood leukaemia. Perhaps to the surprise of the scientific community, the later studies to a great extent confirmed the original finding, although the results have certainly not been identical and indeed some studies failed to find any association. To assess the overall evidence, a pooled analysis was carried out[4] based on primary data from the sub group of nine studies fulfilling certain quality criteria. The principal finding of the pooled analysis was that residential magnetic field exposure in excess of 0.4 μT was associated with about a doubling in the relative risk of childhood leukaemia. It was concluded that chance was an unlikely explanation, but that systematic error could explain some of the observed excess risk.

In parallel with the childhood cancer research, possible associations between other implicated diseases and ELF fields have been explored. Most of this research was directed towards other forms of cancer: brain tumours, leukaemia in adults, and male and female breast cancer are the forms that have attracted the greatest interest. Despite these efforts, however, results have been inconclusive. Interest has prevailed in relation to breast cancer, which remains a focus of attention. However, a recently completed large study with refined occupational exposure information and oestrogen status data for the cases was entirely negative and this is likely to affect the interest in this research track[5].

Outside the cancer field, cardiovascular disease may be the area that has attracted most of the interest. This was based on physiological experiments which noted that ELF magnetic fields appeared to affect heart rate variability[6]. These experiments were followed by a utility worker study showing that chronic heart disease mortality was not associated with ELF exposure but that arrhythmia and myocardial infarction mortality was[7]. However, several later studies that addressed the issue from different perspectives have failed to replicate these results[8,9].

In parallel with the epidemiological research, extensive *in vivo* and *in vitro* research has also been carried out. Despite intense efforts, this has not resulted in the detection of any new mechanisms of interaction between ELF fields and the human body beyond the induction of electric current, nor a strong candidate for such a mechanism. As a consequence, the epidemiological evidence stands alone.

In an evaluation of carcinogenicity, IARC (The International Agency for Research on Cancer) classified ELF magnetic fields as 2B, which translates to *possible carcinogen*; the basis for this classification was the childhood leukaemia results. In essence, over the years, the childhood leukaemia results have increased in strength. At the same time, the exposure level above which effects are seen has been pushed upwards, implying that only a small proportion of homes are exposed at those levels. Based on the combined control groups in the pooled analysis, this percentage was estimated at less than 1%, and considerably less in the European subset. The evidence for other diseases seems instead to have decreased in strength over the years.

Potential health risks from weak long-term exposure: RF

The situation for RF fields is very different from that for ELF. Whereas early research has looked at people with occupational RF exposure (*e.g.* military personnel), studies that specifically address mobile telephony are few and recent. Although the results of the early occupational studies are mainly negative, they are of limited value in an overall assessment because of restrictions in their designs, particularly with regard to exposure assessment. Thus, this is in essence a new research field. To date, half a dozen epidemiological studies on mobile phone users have been published—with predominantly negative findings. Unlike the ELF area there is no seminal study with clear positive results that drives the research. Instead, the driving force appears to be a concern that this new technology penetrates the world population at high speed and therefore warrants close monitoring. The so-called Stewart report has a comprehensive review of the RF research[10].

To date, there are basically two types of studies on mobile phone users, which differ with respect to how exposure information is obtained. One group of studies uses records from the network operators[11–14]. The operators can provide data on number of years of contract, frequency of calls, duration of calls and also, under certain circumstances, more detailed data about individual subscriptions and calls. The studies that have used these data so far have limited themselves to basic data. Some fundamental problems with this approach are that the contract holder is not always the user of the phone and that additional information such as use of hands-free device is required for a more sophisticated assessment of exposure. The next generation of studies may attempt to combine operator data and data obtained directly from the users. Using operator data is, however, not a trivial approach from the logistic point of view. Indeed the study by Rothman and others was aborted for legal reasons relating to privacy issues and can still only report a 1-year follow up. This renders the study uninformative from the substantive point of view, although it has been important for methodological reasons[15,16].

The other group of studies asks subjects in case-control studies about their phone use[17–20]. More detailed data can in principle be obtained by using this approach. However, recall bias is always a concern in such studies. These case-control studies may also be affected by selection bias. In particular, the studies by Hardell and co-workers have been criticized for the possibility of both selection bias and recall bias[21,22]. Later methodological studies have compared operator data and questionnaire data and showed that subjects systematically over-estimate the amount of phone use, which speaks in favour of using a combined approach[23]. An inherent difficulty in this research is the still limited length of the exposure period for most users and also the recent change from analogue to digital systems with different exposure characteristics; obviously the significance of this change is unknown at present. All these studies have focused on brain tumours although some have looked at other intracranial tumours as well. Overall the results are negative but because of the difficulties mentioned above, and because of some glimmers of associations in two studies, the issue cannot be settled yet[14,24].

RF exposure from base stations has also attracted attention, but this is to a great extent initiated by the public rather than by research interests. Scientists normally observe that the exposure levels from base stations are exceeded by about a thousand times by exposure levels from the phones themselves. Thus, from the scientific view it makes more sense to study exposure from phones. Yet, it is true that base stations give rise to whole body exposure for 24 h a day, for those who stay in the neighbourhood. An inherent problem in these studies that remains to be solved is exposure assessment around base stations[25]. For a variety of reasons, distance from the mast is a virtually meaningless proxy for exposure; thus, such studies cannot be designed in a meaningful way before meters or new exposure assessment models adapted to epidemiological purposes are constructed and made available. To date, several studies on radio and TV transmitters have been published in the scientific literature, but they all share the problems discussed above[26–33]. This research area is still in a very premature state and the results of the published studies are of limited interest.

Just as for ELF fields, the *in vivo* and *in vitro* research has been unable so far to come up with results that convincingly show the presence of some biological effect from exposure to RF fields other than heating. There are, however, some as yet unconfirmed results that warrant further follow up. In particular, for the *in vitro* research, however, there is a problem to separate thermal effects from other effects because of difficulties to design the dosimetry such that temperature is unaffected. This experimental research is currently very intense and results are to be expected in the near future.

Balancing risk

Electromagnetic fields are associated with several of the factors that are known to produce public concern. The fields are invisible; they represent new technology; power line, base station and other sources of exposure are uncontrollable by the exposed individual; for many of the exposure sources, the exposed subject has no direct use of the exposure source. The current scientific situation is one of uncertainty and it is often pointed out that the existence of risks cannot be excluded. Indeed ELF fields were classified by IARC as a possible carcinogen; from the public health point of view, this classification often results in the agent being considered carcinogenic. The evidence for the presence of health risks from RF fields is of course very weak, yet the existence of a risk cannot be excluded. At the same time everyone would agree that modern society is inconceivable without electricity. While some people might disagree about the necessity of mobile phones in particular, most people would still conclude that telecommunications are essential.

This presents decision makers with several dilemmas. Even if the risks from ELF field exposure were taken for granted, it would not follow automatically what actions should be taken. The dilemma is that very few people are exposed at high levels and that the disease for which there is the hardest evidence is very rare. So the decision maker would have to balance the public health benefits and the costs and technical and practical consequences of various schemes that could be considered in order to reduce exposure to the population.

For RF fields, the public health consequences would probably be large if a risk were to be detected. On the other hand, the evidence for a risk is at present very weak—bordering on non-existent. Yet, there are some risk management actions that could be invoked at low cost. Examples are recommendations to use hands-free equipment and to limit calls as much as possible. A particular issue is whether to recommend that children in particular should restrict their use. Such a recommendation would not be based on scientific data specifically pointing towards children being at risk, but rather on some common understanding that children are more sensitive because they are still developing, perhaps combined with the moral concept that one should be more careful with children. However, whether, and by whom, even very low cost actions should be recommended in situations with such weak scientific support for the existence of a risk is currently the topic of intense discussions.

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