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Radiation, Non-Ionizing

ELECTRIC AND MAGNETIC FIELDS AND HEALTH OUTCOMES

Bengt Knave

In recent years interest has increased in the biological effects and possible health outcomes of weak electric and magnetic fields. Studies have been presented on magnetic fields and cancer, on reproduction and on neurobehavioural reactions. In what follows, a summary is given of what we know, what still needs to be investigated and, particularly, what policy is appropriate—whether it should involve no restrictions of exposure at all, “prudent avoidance” or expensive interventions.

What we Know

Cancer

Epidemiological studies on childhood leukaemia and residential exposure from power lines seem to indicate a slight risk increase, and excess leukaemia and brain tumour risks have been reported in “electrical” occupations. Recent studies with improved techniques for exposure assessment have generally strengthened the evidence of an association. There is, however, still a lack of clarity as to exposure characteristics—for example, magnetic field frequency and exposure intermittence; and not much is known about possible confounding or effect-modifying factors. Furthermore, most of the occupational studies have indicated one special form of leukaemia, acute myeloid leukaemia, while others have found higher incidences for another form, chronic lymphatic leukaemia. The few animal cancer studies reported have not given much help with risk assessment, and in spite of a large number of experimental cell studies, no plausible and understandable mechanism has been presented by which a carcinogenic effect could be explained.

Reproduction, with special reference to pregnancy outcomes

In epidemiological studies, adverse pregnancy outcomes and childhood cancer have been reported after maternal as well as paternal exposure to magnetic fields, the paternal exposure indicating a genotoxic effect. Efforts to replicate positive results by other research teams have not been successful. Epidemiological studies on visual display unit (VDU) operators, who are exposed to the electric and magnetic fields emitted by their screens, have been mainly negative, and animal teratogenic studies with VDU-like fields have been too contradictory to support trustworthy conclusions.

Neurobehavioural reactions

Provocation studies on young volunteers seem to indicate such physiological changes as slowing of heart rate and electroencephalogram (EEG) changes after exposure to relatively weak electric and magnetic fields. The recent phenomenon of hypersensitivity to electricity seems to be multifactorial in origin, and it is not clear whether the fields are involved or not. A great variety of symptoms and discomforts has been reported, mainly of the skin and the nervous system. Most of the patients have diffuse skin complaints in the face, such as flush, rosiness, ruddiness, heat, warmth, pricking sensations, ache and tightness. Symptoms associated with the nervous system are also described, such as headache, dizziness, fatigue and faintness, tingling and pricking sensations in the extremities, shortness of breath, heart palpitations, profuse sweatings, depressions and memory difficulties. No characteristic organic neurological disease symptoms have been presented.

Exposure

Exposure to fields occurs throughout society: in the home, at work, in schools and by the operation of electrically powered means of transport. Wherever there are electric wires, electric motors and electronic equipment, electric and magnetic fields are created. Average workday field strengths of 0.2 to 0.4 mT (microtesla) appear to be the level above which there could be an increased risk, and similar levels have been calculated for annual averages for subjects living under or near power lines.

Many people are similarly exposed above these levels, though for shorter periods, in their homes (via electric radiators, shavers, hair-dryers and other household appliances, or stray currents due to imbalances in the electrical grounding system in a building), at work (in certain industries and offices involving proximity to electric and electronic equipment) or while travelling in trains and other electrically driven conveyances. The importance of such intermittent exposure is not known. There are other uncertainties as to exposure (involving questions relating to the importance of field frequency, to other modifying or confounding factors, or to knowledge of the total exposure day and night) and effect (given the consistency in findings as to type of cancer), and in the epidemiological studies, which make it necessary to evaluate all risk assessments with great caution.

Risk assessments

In Scandinavian residential studies, results indicate a doubled leukaemia risk above 0.2 mT, the exposure levels corresponding to those typically encountered within 50 to 100 metres of an overhead power line. The number of childhood leukaemia cases under power lines are few, however, and the risk is therefore low compared to other environmental hazards in society. It has been calculated that each year in Sweden there are two cases of childhood leukaemia under or near power lines. One of these cases may be attributable to the magnetic field risk, if any.

Occupational exposures to magnetic fields are generally higher than residential exposures, and calculations of leukaemia and brain tumour risks for exposed workers give higher values than for children living close to power lines. From calculations based on the attributable risk discovered in a Swedish study, approximately 20 cases of leukaemia and 20 cases of brain tumours could be attributed to magnetic fields each year. These figures are to be compared with the total number of 40,000 annual cancer cases in Sweden, of which 800 have been calculated to have an occupational origin.

What Still Needs to be Investigated

It is quite clear that more research is needed in order to secure a satisfactory understanding of the epidemiological study results obtained so far. There are additional epidemiological studies in progress in different countries around the world, but the question is whether these will add more to the knowledge we already have. As a matter of fact it is not known which characteristics of the fields are causal to the effects, if any. Thus, we definitely need more studies on possible mechanisms to explain the findings we have assembled.

There are in the literature, however, a vast number of in vitro studies devoted to the search for possible mechanisms. Several cancer promotion models have been presented, based on changes in the cell surface and in the cell membrane transport of calcium ions, disruption of cell communication, modulation of cell growth, activation of specific gene sequences by modulated ribonucleic acid (RNA) transcription, depression of pineal melatonin production, modulation of ornithine decarboxylase activity and possible disruption of hormonal and immune-system anti-tumour control mechanisms. Each of these mechanisms has features applicable to explaining reported magnetic field cancer effects; however, none has been free of problems and essential objections.

Melatonin and magnetite

There are two possible mechanisms that may be relevant to cancer promotion and thus deserve special attention. One of these has to do with the reduction of nocturnal melatonin levels induced by magnetic fields and the other is related to the discovery of magnetite crystals in human tissues.

It is known from animal studies that melatonin, via an effect on circulating sex hormone levels, has an indirect oncostatic effect. It has also been indicated in animal studies that magnetic fields suppress pineal melatonin production, a finding that suggests a theoretical mechanism for the reported increase in (for example) breast cancer that may be due to exposure to such fields. Recently, an alternative explanation for the increased cancer risk has been proposed. Melatonin has been found to be a most potent hydroxyl radical scavenger, and consequently the damage to DNA that might be done by free radicals is markedly inhibited by melatonin. If melatonin levels are suppressed, for example by magnetic fields, the DNA is left more vulnerable to oxidative attack. This theory explains how the depression of melatonin by magnetic fields could result in a higher incidence of cancer in any tissue.

But do human melatonin blood levels diminish when individuals are exposed to weak magnetic fields? There exist some indications that this may be so, but further research is needed. For some years it has been known that the ability of birds to orient themselves during seasonal migrations is mediated via magnetite crystals in cells that respond to the earth's magnetic field. Now, as mentioned above, magnetite crystals have also been demonstrated to exist in human cells in a concentration high enough theoretically to respond to weak magnetic fields. Thus the role of magnetite crystals should be considered in any discussions on the possible mechanisms that may be proposed as to the potentially harmful effects of electric and magnetic fields.

The need for knowledge on mechanisms

To summarize, there is a clear need for more studies on such possible mechanisms. Epidemiologists need information as to which characteristics of the electric and magnetic fields they should focus upon in their exposure assessments. In most epidemiological studies, mean or median field strengths (with frequencies of 50 to 60 Hz) have been used; in others, cumulative measures of exposure were studied. In a recent study, fields of higher frequencies were found to be related to risk. In some animal studies, finally, field transients have been found to be important. For epidemiologists the problem is not on the effect side; registers on diseases exist in many countries today. The problem is that epidemiologists do not know the relevant exposure characteristics to consider in their studies.

What Policy is Appropriate

Systems of protection

Generally, there are different systems of protection to be considered with respect to regulations, guidelines and policies. Most often the health-based system is selected, in which a specific adverse health effect can be identified at a certain exposure level, irrespective of exposure type, chemical or physical. A second system could be characterized as an optimization of a known and accepted hazard, which has no threshold below which the risk is absent. An example of an exposure falling within this kind of system is ionizing radiation. A third system covers hazards or risks where causal relationships between exposure and outcome have not been shown with reasonable certainty, but for which there are general concerns about possible risks. This lattermost system of protection has been denoted the principle of caution, or more recently prudent avoidance, which can be summarized as the future low-cost avoidance of unnecessary exposure in the absence of scientific certainty. Exposure to electric and magnetic fields has been discussed in this way, and systematic strategies have been presented, for instance, on how future power lines should be routed, workplaces arranged and household appliances designed in order to minimize exposure.

It is apparent that the system of optimization is not applicable in connection with restrictions of electric and magnetic fields, simply because they are not known and accepted as risks. The other two systems, however, are both presently under consideration.

Regulations and guidelines for restriction of exposure under the health-based system

In international guidelines limits for restrictions of field exposure are several orders of magnitude above what can be measured from overhead power lines and found in electrical occupations. The International Radiation Protection Association (IRPA) issued Guidelines on limits of exposure to 50/60 Hz electric and magnetic fields in 1990, which has been adopted as a basis for many national standards. Since important new studies were published thereafter, an addendum was issued in 1993 by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Furthermore, in 1993 risk assessments in agreement with that of IRPA were also made in the United Kingdom.

These documents emphasize that the state of scientific knowledge today does not warrant limiting exposure levels for the public and the workforce down to the mT level, and that further data are required to confirm whether or not health hazards are present. The IRPA and ICNIRP guidelines are based on the effects of field-induced currents in the body, corresponding to those normally found in the body (up to about 10 mA/m2). Occupational exposure to magnetic fields of 50/60 Hz is recommended to be limited to 0.5 mT for all-day exposure and 5 mT for short exposures of up to two hours. It is recommended that exposure to electric fields be limited to 10 and 30 kV/m. The 24-hour limit for the public is set at 5 kV/m and 0.1 mT.

These discussions on the regulation of exposure are based entirely on cancer reports. In studies of other possible health effects related to electric and magnetic fields (for example, reproductive and neurobehavioural disorders), results are generally considered insufficiently clear and consistent to constitute a scientific basis for restricting exposure.

The principle of caution or prudent avoidance

There is no real difference between the two concepts; prudent avoidance has been used more specifically, though, in discussions of electric and magnetic fields. As said above, prudent avoidance can be summarized as the future, low-cost avoidance of unnecessary exposure as long as there is scientific uncertainty about the health effects. It has been adopted in Sweden, but not in other countries.

In Sweden, five government authorities (the Swedish Radiation Protection Institute; the National Electricity Safety Board; the National Board of Health and Welfare; the National Board of Occupational Safety and Health; and the National Board of Housing, Building and Planning) jointly have stated that "the total knowledge now accumulating justifies taking steps to reduce field power". Provided the cost is reasonable, the policy is to protect people from high magnetic exposures of long duration. During the installation of new equipment or new power lines that may cause high magnetic field exposures, solutions giving lower exposures should be chosen provided these solutions do not imply large inconveniences or costs. Generally, as stated by the Radiation Protection Institute, steps can be taken to reduce the magnetic field in cases where the exposure levels exceed the normally occurring levels by more than a factor of ten, provided such reductions can be done at a reasonable cost. In situations where the exposure levels from existing installations do not exceed the normally occurring levels by a factor of ten, costly rebuilding should be avoided. Needless to say, the present avoidance concept has been criticized by many experts in different countries, such as by experts in the electricity supply industry.

Conclusions

In the present paper a summary has been given of what we know on the possible health effects of electric and magnetic fields, and what still needs to be investigated. No answer has been given to the question of which policy should be adopted, but optional systems of protection have been presented. In this connection, it seems clear that the scientific database at hand is insufficient to develop limits of exposure at the mT level, which means in turn that there are no reasons for expensive interventions at these exposure levels. Whether some form of strategy of caution (e.g., prudent avoidance) should be adopted or not is a matter for decisions by public and occupational health authorities of individual countries. If such a strategy is not adopted it usually means that no restrictions of exposure are imposed because the health-based threshold limits are well above everyday public and occupational exposure. So, if opinions differ today as to regulations, guidelines and policies, there is a general consensus among standard setters that more research is needed to get a solid basis for future actions.