Available online at www.sciencedirect.com
ScienceDirect
Biomedicine & Pharmacotherapy 62 (2008) 104–109
BIOMEDICINE & PHARMACOTHERAPY
www.elsevier.com/locate/biopha

Original article

Biological effects from electromagnetic field exposure and public exposure standards☆,☆☆

Lennart Hardell [a,*], Cindy Sage [b]

[a] Department of Oncology, University Hospital, SE-701 85 Örebro, Sweden
[b] Sage Associates, Santa Barbara, CA, USA

Received 6 December 2007; accepted 12 December 2007
Available online 31 December 2007

Abstract

During recent years there has been increasing public concern on potential health risks from power-frequency fields (extremely low frequency electromagnetic fields; ELF) and from radiofrequency/microwave radiation emissions (RF) from wireless communications. Non-thermal (low-intensity) biological effects have not been considered for regulation of microwave exposure, although numerous scientific reports indicate such effects. The BioInitiative Report is based on an international research and public policy initiative to give an overview of what is known of biological effects that occur at low-intensity electromagnetic fields (EMFs) exposure. Health endpoints reported to be associated with ELF and/or RF include childhood leukaemia, brain tumours, genotoxic effects, neurological effects and neurodegenerative diseases, immune system deregulation, allergic and inflammatory responses, breast cancer, miscarriage and some cardiovascular effects. The BioInitiative Report concluded that a reasonable suspicion of risk exists based on clear evidence of bioeffects at environmentally relevant levels, which, with prolonged exposures may reasonably be presumed to result in health impacts. Regarding ELF a new lower public safety limit for habitable space adjacent to all new or upgraded power lines and for all other new constructions should be applied. A new lower limit should also be used for existing habitable space for children and/or women who are pregnant. A precautionary limit should be adopted for outdoor, cumulative RF exposure and for cumulative indoor RF fields with considerably lower limits than existing guidelines, see the BioInitiative Report. The current guidelines for the US and European microwave exposure from mobile phones, for the brain are 1.6 W/Kg and 2 W/Kg, respectively. Since use of mobile phones is associated with an increased risk for brain tumour after 10 years, a new biologically based guideline is warranted. Other health impacts associated with exposure to electromagnetic fields not summarized here may be found in the BioInitiative Report at www.bioinitiative.org.

Keywords: Electromagnetic fields (EMFs); Extremely low frequency electromagnetic fields (ELF); Radiofrequency fields (RF); Carcinogenesis; Public health; Standard setting

1. Introduction

During recent years there has been increasing scientific evidence for, and public concern on potential health risks from power-frequency fields (extremely low frequency electromagnetic fields; ELF) and from radiofrequency/microwave radiation emissions (RF) from wireless communications and data transmission. So far, guidelines for exposure to microwaves have been based on thermal (heating) effects. Non-thermal (low-intensity) effects have not been considered for regulation of exposure. Recently a more comprehensive report was published at Internet [1] that documents considerable scientific evidence for bioeffects and adverse health impacts at exposure levels far below current public safety standards. The purpose of that report was to assess scientific evidence on health impacts from electromagnetic radiation below current public exposure limits and evaluate what changes in these limits are warranted now to reduce possible

☆ *Note:* the views expressed in this paper are not necessarily those of the whole BioInitiative Report group. Some parts of this article rely on chapters by different authors in the BioInitiative Report.
☆☆ This manuscript is a part of the dossier ''Cancer: Influence of environment'', Biomedicine & Pharmacotherapy 2007;61:10.
* Corresponding author. Tel.: +46 19 602 10 00; fax: +46 19 10 17 68.
E-mail address: lennart.hardell@orebroll.se (L. Hardell).

0753-3322/$ - see front matter © 2007 Elsevier Masson SAS. All rights reserved.
doi:10.1016/j.biopha.2007.12.004

public health risks in the future. This report was written by 14 scientists, public health and public policy experts to document the scientific evidence on electromagnetic fields. The current short review is based on the BioInitiative Report and gives summaries of relevant topics. For more details including complete reference list, see that document at http://www.bioinitiative.org.

Everyone is exposed to two types of electromagnetic fields (EMFs): (a) ELF fields from electrical and electronic appliances and power lines, and (b) RF radiation from wireless devices such as cell phones and cordless phones, cellular antennas and towers, and broadcast transmission towers. In this report we will use the term EMFs when referring to all electromagnetic fields in general, and the terms ELF and RF when referring to the specific type of exposure. They are both types of non-ionizing radiation, which means that they do not have sufficient energy to break off electrons from their orbits around atoms and ionize (charge) the atoms, as ionizing radiation.

2. Materials and results

2.1. Mobile phone use and evidence for brain tumours and acoustic neuroma

We made a review including 18 studies, two cohort studies and 16 case-control studies. Most studies have published data with rather short latency period and limited information on long-term users. Thus, a meta-analysis of the risk for acoustic neuroma, glioma and meningioma was performed for mobile phone use with a latency period of 10 years or more [2]. Overall OR = 1.3, 95% CI = 0.6–2.8 was obtained increasing to OR = 2.4, 95% CI = 1.1–5.3 for ipsilateral mobile phone use. For glioma OR = 1.2, 95% CI = 0.8–1.9 was calculated. Ipsilateral use yielded OR = 2.0, 95% CI = 1.2–3.4. In total OR = 1.3, 95% CI = 0.9–1.8 was found for meningioma increasing to OR = 1.7, 95% CI = 0.99–3.1 for ipsilateral use. Only two studies have been published since then. Both were on acoustic neuroma [3,4]. They were small and included no cases with a latency period of at least 10 years. Furthermore, most ORs were <1.0 in these two studies indicating serious methodological problems. The final results on this topic from the Interphone study led by the International Agency for Research on Cancer (IARC) are expected during 2008.

No other studies than from the Hardell group has published results for use of cordless phones (DECT) [5,6]. As we have discussed in our publications it is pertinent to include also such use in this type of studies. Cordless phones are an important source of exposure to radiofrequency microwaves and they are usually used for a longer time period on daily basis as compared with mobile phones. Thus, to exclude such use, as was done in e.g. the Interphone studies, could lead to an underestimation of the risk for brain tumours from use of wireless phones.

In summary our review yielded a consistent pattern of an increased risk for acoustic neuroma and glioma after ≥10 years mobile phone use. We conclude that current standard for exposure to microwaves during mobile phone use is not safe for long-term exposure and needs to be revised.

2.2. RF fields other than from mobile phones and epidemiological evidence for brain tumours

It is concluded that only few studies of long-term exposure to low levels of RF fields and brain tumours exist, all of which have methodological shortcomings including lack of quantitative exposure assessment. Given the crude exposure categories and the likelihood of a bias towards the null hypothesis of no association, the body of evidence is consistent with a moderately elevated risk. Occupational studies indicate that long-term exposure at workplaces may be associated with an elevated brain tumour risk.

Although in some occupations (especially in military jobs) current exposure guidelines may have sometimes been reached or exceeded, overall the evidence suggests that long-term exposure to levels generally lying below current guideline levels still carry the risk of increasing the incidence of brain tumours.

Despite a rather low population attributable risk (likely below 4%), still more than 1000 cases per year in the US can be attributed to RF exposure at workplaces alone.

2.3. Evidence for childhood cancers and leukaemia

The only endpoint studied so far in sufficient detail is childhood leukaemia. Brain and nervous system tumours were also studied in some detail but due to the diversity of these tumours no conclusions can be drawn. Childhood leukaemia is the most frequent childhood malignancy that peaks in the age group of 2 to about 5 years. This peak seems to have been newly evolved in the early quarter of the 20th century and may be due to electrification [7]. This assumption is supported by the absence of this peak or it being much less pronounced in developing countries.

An overview of existing evidence from epidemiological studies indicates that there is a continuous increase of risk with increasing levels of average magnetic field exposure. Risk estimates reach statistical significance at levels of 3–4 mG (0.3–0.4 microTesla or μT). The overall odds ratio in nine studies was 2.1, 95% confidence limit 1.3–3.3. A low number of children are exposed at these or higher levels.

The balance of evidence suggests that childhood leukaemia is associated with exposure to power-frequency ELFs either during pregnancy or early life. Considering only average MF flux densities the population attributable risk is low to moderate. However, there is a possibility that other exposure metrics are much stronger related to childhood leukaemia and may account for a substantial proportion of cases, perhaps up to 80% of all cases. The population attributable fraction ranges between 1 and 4% [8] assuming only exposures above 3–4 mG (0.3–0.4 μT) are relevant.

Other childhood cancers except leukaemia have not been studied in sufficient detail to allow conclusions about the existence and magnitude of the risk.

The International Commission for Non-ionizing Radiation Protection (ICNIRP) and Institute of Electric and Electronics Engineers, Inc. (IEEE) guideline levels are designed to protect from short-term immediate effects only, but not chronic exposures. Long-term effects such as cancer are evoked by exposure several orders of magnitudes below current guideline levels. The BioInitiative Report concludes that the evidence for increased risk of childhood leukaemia with chronic exposure to ELFs is sufficient to warrant revision of ELF public safety limits.

2.4. Breast cancer

There is evidence from multiple areas of scientific investigations that ELF is related to breast cancer. Over the last two decades there have been numerous epidemiological studies on breast cancer in both men and women, although this relationship remains controversial. Many of these studies, however, report that ELF exposures are related to increased risk of breast cancer.

The evidence from studies on women in workplaces suggests that ELF is a risk factor for breast cancer for women with long-term exposures of 10 mG (1.0 μT) and higher.

Laboratory studies that examine human breast cancer cells have shown that ELF exposure between 6 mG and 12 mG (0.6–1.2 μT) can interfere with protective effects of melatonin for the growth of these breast cancer cells. For a decade, there has been evidence that human breast cancer cells grow faster if exposed to ELF at low environmental levels. This is thought to be because ELF exposure can reduce melatonin levels in the body.

Laboratory studies of animals that have breast cancer tumours have been shown to have more tumours and larger tumours when exposed to ELF and a chemical tumour promoter at the same time. These studies taken together indicate that ELF is a likely risk factor for breast cancer, and that ELF levels of importance are no higher than many people are exposed to at home and at work. A reasonable suspicion of risk exists and is sufficient evidence on which to recommend new ELF limits; and to warrant preventative action.

Given the very high lifetime risks for developing breast cancer in women, and the critical importance of prevention, ELF exposures should be reduced for all people who are in high ELF environments for prolonged periods of time. Reducing ELF exposure would be particularly important for people who have breast cancer. The recovery environment should have low ELF levels given the evidence for poorer survival rates as shown for subjects with another malignant disease, childhood leukaemia patients in ELF fields over 2 mG or 3 mG (0.2 or 0.3 μT).

Preventative action for those who may be at higher risk for breast cancer is also warranted, particularly for those taking tamoxifen during their anti-cancer treatment, since in addition to reducing the effectiveness of melatonin, ELF exposure may also reduce the effectiveness of tamoxifen at these same low exposure levels. There is no excuse for ignoring the substantial body of evidence we already have that supports an association between breast cancer and ELF exposure; waiting for conclusive evidence is untenable given the enormous costs and societal and personal burdens caused by this disease.

2.5. Changes in the nervous system and brain function

Exposure to electromagnetic fields has been studied in connection with Alzheimer's disease, motor neuron disease and Parkinson's disease. There is evidence that high level of amyloid beta is a risk factor for Alzheimer's disease, and exposure to ELF can increase this substance in the brain. There is considerable evidence that melatonin can protect the brain against damage leading to Alzheimer's disease, and also strong evidence that exposure to ELF can reduce melatonin levels. Thus it is hypothesized that one of the body's main protections against developing Alzheimer's disease (melatonin) is less available to the body when people are exposed to ELF. Prolonged exposure to ELF fields could alter calcium (Ca^{2+}) levels in neurons and induce oxidative stress. Concern has also been raised that humans with epileptic disorders could be more susceptible to RF exposure.

Laboratory studies show that the nervous system of both humans and animals is sensitive to both ELF and RF. Measurable changes in brain function and behaviour occur at levels associated with new technologies including cell phone use. Exposing humans to cell phone radiation can change brainwave activity at levels as low as 0.1 watt per kilogram (W/Kg) specific absorption rate (SAR) in comparison to the US allowable level of 1.6 W/Kg (in 1 g of tissue) and ICNIRP allowable level of 2.0 W/Kg (in 10 g of tissue). Cell phone radiation can affect memory and learning.

Changes in the way in which the brain and nervous system react depend very much on the specific exposures. Most studies only look at short-term effects, so the long-term consequences of exposures are not established, but existing scientific documentation of effects is sufficient to warrant preventative action with reduction in exposures, particularly for vulnerable groups such as children [9].

Factors that determine effects can depend on head shape and size, the location, size and shape of internal brain structures, thinness of the head and face, hydration of tissues, thickness of various tissues, dielectric constant of the tissues and so on. Age of the individual and state of health also appear to be important variables.

There is large variability in the results of ELF and RF testing, which would be expected to be based on the large variability of factors that can influence test results. However, it is clearly demonstrated that under some conditions of exposure, the brain and nervous system functions of humans are altered. The consequence of long-term or prolonged exposures has not been thoroughly studied in either adults or in children.

The consequence of prolonged exposures to children, whose nervous systems continue to develop until late adolescence, is unknown at this time, but there are credible, published studies reporting bioeffects and adverse health impacts with exposures at very low levels (far below public safety standards). This could have serious implications to adult health and functioning in society if years of exposure of the young to both ELF and RF

result in diminished capacity for thinking, judgment, memory, learning, and control over behaviour.

2.6. Evidence for effects on gene and protein expression

The effects of RF EMF on global gene and protein expression have been investigated in different biological systems, and most of the studies were focused on the mobile phone utilization frequency (800–2000 MHz) at a relatively low exposure density (average SAR near 2.0 W/Kg). Some studies reported negative results of RF EMF exposure on gene expression.

Based on current available literature, it is justified to conclude that EMF exposure can change gene and/or protein expression in certain types of cells, even at intensities lower than ICNIRP recommended values. However, the biological consequences of most of the changed genes/proteins as based on early studies from proteomics and transcriptomics are still unclear, and need to be further explored. Thus, it is not the time point yet to assess the health impact of EMF based on the gene and protein expression data. The IEEE and WHO databases do not include the majority of ELF studies; they do include the majority of the RF studies.

Currently, the state of proteomics and transcriptomics is in its infancy, with only a few dozen studies reporting results, some positive and some negative. The EMF research community should pay equal attention to the negative reports as to the positive ones. Not only the positive findings need to be replicated, the negative ones need to be critically assessed and replicated too.

2.7. Evidence for genotoxic effects – DNA damage

From this literature survey, about 50% of the studies reported effects. Not every study, however, would be expected to document effects, given the wide range of exposure conditions and varying sensitivity of assays. One can conclude that under certain conditions of exposure, radiofrequency radiation is genotoxic. Data available are mainly applicable only to cell phone radiation exposure. Other than the study by Phillips et al. [10], there are very few published studies of RF radiation at levels that one can experience in the vicinity of base stations and RF-transmission towers.

During cell phone use, a relatively constant mass of tissue in the brain is exposed to the radiation at relatively high intensity (peak SAR of 4–8 W/Kg). Several studies reported DNA damage at lower intensity than 4 W/Kg. The IEEE has revised its recommended standard for localized tissue exposure, changing it from 1.6 W/Kg over 1 g of tissue to 2 W/Kg over 10 g of tissue, although the Federal Communications Commission has not adopted this change. Since distribution of radiofrequency energy is non-homogenous inside tissue, this change allows a higher peak level of exposure. Furthermore, since critical genetic mutations in one single cell are sufficient to lead to cancer and there are millions of cells in a gram of tissue, it is inconceivable that the base of SAR standard was changed by IEEE from averaged over 1 gm of tissue to 10 gm.

Factors that may explain the failure of some studies to demonstrate effects, while others report clear and reproducible effects include (a) which DNA assay is used, (b) the exposure parameters of the experiment, and (c) which cell lines are used. Any effect of EMF has to depend on the energy absorbed by a biological entity and on how the energy is delivered in space and time. Frequency, intensity, exposure duration, and the number of exposure episodes can affect the response, and these factors can interact with each other to produce different effects.

The 'comet assay', has been used in most of the EMF studies to determine DNA damage. Different versions of the assay have been developed. These versions have different detection sensitivities and can be used to measure different aspects of DNA strand breaks. A comparison of data from experiments using different versions of the assay may be misleading, and may explain differing study results since some DNA comet assays are far more sensitive in detecting DNA damage than other assays.

A plausible biological mechanism to account for carcinogenesis is via free radical formation inside cells. Free radicals kill cells by damaging macromolecules, such as DNA, protein and membrane. Furthermore, free radicals play an essential role in the activation of certain signalling pathways. Several reports have indicated that EMFs enhance free radical activity in cells particularly via the Fenton reaction [11]. The Fenton reaction is a catalytic process of iron to convert hydrogen peroxides, a product of oxidative respiration in the mitochondria, into hydroxyl free radical, which is a very potent and toxic free radical. Any exposure, including prolonged low-intensity ELF and RF exposures that result in increased free radical production may be considered a plausible biological mechanism for carcinogenesis.

2.8. Evidence for stress response

Studies of the stress response in different cells under various conditions have enabled us to characterize the molecular mechanisms by which cells respond to EMF and their effects on health risk. That information can now correct assumptions about biological effects of EMF, and establish a scientific basis for new safety standards.

It is generally agreed that EMF safety standards should be based on science, yet recent EMF research has shown that a basic assumption used to determine EMF safety is not valid. The safety standard assumes that EMF causes biological damage only by heating, but cell damage occurs in the absence of heating and well below the safety limits. This has been shown in many studies, including the cellular stress response where cells synthesize stress proteins in reaction to potentially harmful stimuli in the environment, including EMF. The stress response to both the power-frequency (ELF) and radiofrequency/microwave (RF) ranges shows the inadequacy of the thermal SAR standard.

The stress response is a natural defence mechanism activated by molecular damage caused by environmental forces. The response involves activation of DNA, i.e., stimulating stress genes

as well as genes that sense and repair damage to DNA and proteins. Scientific research has identified specific segments of DNA that respond to both ELF and RF. It has been possible to move these specific segments of DNA and transfer the sensitivity to EMF. At high EMF intensities, the interaction with DNA can lead to DNA strand breaks that could result in mutation, an initiating step in the development of cancer.

Scientific research has shown that ELF and RF fields interact with DNA to stimulate protein synthesis, and at higher intensities to cause DNA damage. The biological thresholds (field strength, duration) are well below current safety limits. To be in line with EMF research, a biologically based standard must replace the thermal SAR standard, which is fundamentally flawed. EMF research also indicates a need for protection against the cumulative biological effects stimulated by EMF across the electromagnetic spectrum.

3. Discussion

3.1. Key scientific evidence

Exposure to EMFs has been linked to a variety of adverse health outcomes. There are other effects not summarized here, see the BioInitiative Report [1]. Health endpoints that have been reported to be associated with ELF and/or RF include childhood leukaemia, adult brain tumours, childhood brain tumours, genotoxic effects (DNA damage and micronucleation), neurological effects and neurodegenerative diseases, immune system deregulation, allergic and inflammatory responses, breast cancer in men and women, miscarriage and some cardiovascular effects.

Effects are not specifically segregated for ELF or RF, since many overlapping exposures occur in daily life, and because this is an artificial division based on frequencies as defined in physics that have little bearing on the biological effects. Both ELF and RF, for example have been shown to cause cells to generate stress proteins, a universal sign of distress in plant, animal and human cells, and to cause DNA damage and neurological impacts at levels far below current safety standards.

3.2. Public health policy recommendations

There are many historical examples of scientifically based early warnings about potential health effects from environmental hazards and a long time period until precautionary and preventive measures were undertaken [12]. Vested interests may thereby counteract necessary public health actions [13]. The precautionary principle should be used when there is reasonable ground for concern. Based on the BioInitiative Report [1], this criterion is fulfilled regarding exposure to electromagnetic fields, both extremely low frequency electromagnetic and radiofrequency fields.

New regulatory limits for ELF based on biologically relevant levels of ELF are warranted, see the BioInitiative Report. ELF limits should be set below those exposure levels that have been linked in childhood leukaemia studies to increased risk of disease, plus an additional safety factor. It is no longer acceptable to build new power lines and electrical facilities that place people in ELF environments that have been associated with an increased risk of adverse health effects, levels generally at 2 mG (0.2 μT) and above.

A new, lower planning limit for habitable space adjacent to all new or upgraded power lines and for all other new construction should be applied. A lower limit should also be used for existing habitable space for children and/or women who are pregnant. This recommendation is based on the assumption that a higher burden of protection is required for children who cannot protect themselves, and who are at risk for childhood leukaemia at rates that are traditionally high enough to trigger regulatory action.

While it is not realistic to reconstruct all existing electrical distributions systems in the short-term, steps to reduce exposure from these existing systems need to be initiated, especially in places where children spend time, and should be encouraged.

A precautionary limit should be adopted for outdoor, cumulative RF exposure and for cumulative indoor RF fields with considerably lower limits than existing guidelines. It should reflect the current RF science and prudent public health response that would reasonably be set for pulsed RF (ambient) exposures where people live, work and go to school. This level of RF is experienced as whole-body exposure, and can be a chronic exposure where there is wireless coverage present for voice and data transmission for cell phones, pagers and personal digital assistants (PDAs) and other sources of radiofrequency radiation. Although this RF target level does not preclude further rollout of WI-FI technologies, wired alternatives to WI-FI should be implemented, particularly in schools and libraries so that children are not subjected to elevated RF levels until more is understood about possible health impacts. This recommendation should be seen as an interim precautionary limit that is intended to guide preventative actions. More conservative limits may be needed in the future.

The current guideline for microwave exposure from mobile phones in Europe is 2 W/Kg for the brain. This is based on thermal effect using cataract development in animal eyes induced at 100 W/Kg with a safety factor of 50 for standard setting. There were also considerations about the relationship between the whole-body SAR and local hot spots and local SAR in relation to whole-body SAR. Since use of mobile phones is associated with an increased risk for brain tumours (glioma, acoustic neuroma) after 10 years a new biologically based guideline should be applied. This new guideline should be based on non-thermal (low-intensity) effects from microwave exposure. It should be added that in toxicology normal practice is to add a safety limit of at least factor 100, which is factor 10 from animal to human beings and factor 10 for individual variability [14].

Exposure from base stations for DECT phones are not specifically addressed in the BioInitiative Report. However, we conclude that indoor exposure to RF should be assessed as well as exposure while using DECT phones. There is indication of increased brain tumour risk associated with DECT phones and a safety factor is warranted both for these phones

and indoor base station exposures. The same standard might be applied to cordless phones as for a new guideline for mobile phones based on biological effects. This is a reasonable suggestion to address the condition where occupied interior space is affected by DECT phones or other RF-emitting devices installed by the occupants. As with ELF fields also for RF fields different limits may be needed in the future as science progresses.

Acknowledgments

Supported by grants from a private philanthropic organization administered by Commonweal, Bolinas, California, USA, and from Cancer-och Allergifonden, Sweden. The paper is based on the BioInitiative Report, and its individual chapters by the authors of this article, and by Carl F. Blackman, PhD, Martin Blank, PhD, Professor, David Gee, European Environmental Agency, Michael Kundi, PhD med. habil. Professor, David O. Carpenter, MD, Zoreh Davanipour, DVM, PhD, Olle Johansson, PhD, Associate Professor, Henry Lai, PhD, Kjell Hansson Mild, PhD, Professor, Amy Sage, BS, Research Associate, Eugene L. Sobel, PhD, Zhengping Xu, PhD, and Guangdi Chen, PhD.

References

[1] BioInitiative report: a rationale for a biologically-based public exposure standard for electromagnetic fields (ELF and RF). http://www.bioinitiative.org [accessed 22.10.07].

[2] Hardell L, Carlberg M, Söderqvist F, Hansson Mild K, Morgan LL. Long-term use of cellular phones and brain tumours: increased risk associated with use for ≥10 years. Occup Environ Med 2007;64:626–32. doi:10.1136/oem.2006.029751.

[3] Klaeboe L, Blaasaas KG, Tynes T. Use of mobile phones in Norway and risk of intracranial tumours. Eur J Cancer Prev 2007;16:158–64.

[4] Schlehofer B, Schlafer K, Blettner M, Berg G, Böhler F, Hettinger I, et al. Environmental risk factors for sporadic acoustic neuroma (Interphone Study Group, Germany). Eur J Cancer 2007;43(11):1741–7. doi:10.1016/j.ejca.2007.05.008.

[5] Hardell L, Carlberg M, Hansson Mild K. Pooled analysis of two case-control studies on the use of cellular and cordless telephones and the risk of benign tumours diagnosed during 1997–2003. Int J Oncol 2006;28:509–18.

[6] Hardell L, Hansson Mild K, Carlberg M. Pooled analysis of two case-control studies on use of cellular and cordless telephones and the risk for malignant brain tumours diagnosed in 1997–2003. Int Arch Occup Environ Health 2006;79:630–9.

[7] Milham S, Ossiander EM. Historical evidence that residential electrification caused the emergence of the childhood leukemia peak. Med Hypotheses 2001;56:290–5.

[8] Kheifets L, Afifi AA, Shimkhada R. Public health impact of extremely low frequency electromagnetic fields. Environ Health Perspect 2006;114(10):1532–7.

[9] European Environmental Agency. Highlights: European Environmental Agency website by Dr. Jacqueline McGlade, Director. Statement of September 17, 2007. www.eea.europa.eu/themes/human [accessed 22.10.07].

[10] Phillips JL, Ivaschuk O, Ishida-Jones T, Jones RA, Campbell-Beachler M, Haggren W. DNA damage in Molt-4 T-lymphoblastoid cells exposed to cellular telephone radiofrequency fields in vitro. Bioelectrochem Bioenerg 1998;45:103–10.

[11] Lai H, Singh NP. Magnetic-field-induced DNA strand breaks in brain cells of the rat. Environ Health Perspect 2004;112(6):687–94.

[12] European Environment Agency. Late lessons from early warnings: the precautionary principle 1896–2000. Copenhagen, Denmark. Environmental issue report 2001, No. 22. http://reports.eea.europa.eu/environmental_issue_report_2001_22/en [accessed 22.10.07].

[13] Hardell L, Walker M, Walhjalt B, Friedman LS, Richter ED. Secret ties to industry and conflicting interests in cancer research. Am J Ind Med 2007;50:227–33.

[14] Scinicariello F, De Rosa CT. Genetic heterogeneity and its effect on susceptibility to environmental factors. Eur J Oncol 2007;12(3):155–70.