Review

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Human disease resulting from exposure to electromagnetic fields[1)]

Abstract: Electromagnetic fields (EMFs) include everything from cosmic rays through visible light to the electric and magnetic fields associated with electricity. While the high frequency fields have sufficient energy to cause cancer, the question of whether there are human health hazards associated with communication radiofrequency (RF) EMFs and those associated with use of electricity remains controversial. The issue is more important than ever given the rapid increase in the use of cell phones and other wireless devices. This review summarizes the evidence stating that excessive exposure to magnetic fields from power lines and other sources of electric current increases the risk of development of some cancers and neurodegenerative diseases, and that excessive exposure to RF radiation increases risk of cancer, male infertility, and neurobehavioral abnormalities. The relative impact of various sources of exposure, the great range of standards for EMF exposure, and the costs of doing nothing are also discussed.

Keywords: cancer; cell phones; male fertility; power lines.

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Introduction

Electromagnetic fields (EMFs) are packets of energy that have no mass. The form of EMFs we all know best is visible light. We distinguish red from violet because the EMFs that we see as red have a longer wavelength than those we see as violet, and the visual pigments in our retina distinguishes these colors on the basis of the wavelength. All EMFs travel at the speed of light, and are basically sine waves of different frequencies. As such, an EMF that is of low frequency has a long wavelength, while those with a high frequency have a short wavelength. The energy of a particular EMF is a function of its frequency, such that the higher the frequency the greater the energy. Figure 1 shows the electromagnetic spectrum.

At the high end of the EMF spectrum, we have X-rays, gamma rays, and cosmic rays. These have a very high frequency and a very short wavelength. They also have very high energy levels, sufficient to directly damage DNA and every other biological molecule, including breaking water molecules. Given that many of these actions are mediated by breaking water molecules into reactive oxygen species (ROS) or free radicals, these high energy EMFs are identified as a form of "ionizing" radiation. They can induce similar kinds of cellular damage as do particulate ionizing radiation (α, β, and γ particles). We are all continuously exposed to ionizing EMFs at low exposure levels, which come from cosmic rays from space as well as from the disintegration of natural radioactive isotopes in our environment and even within our bodies. Ionizing radiation, whether in the form of EMFs or particulate radiation, causes cellular damage and increases the risk of a variety of diseases, particularly cancer and birth defects. There is some evidence in support of the hypothesis that the basic mechanism behind the aging process is the accumulation of cell damage coming from ionizing radiation and other sources (1).

As frequencies are reduced from the ionizing portion of the electromagnetic spectrum we have ultraviolet radiation, which is known to induce skin cancer with excessive exposure, then visible light and infrared radiation which heat the earth. Clearly, life on earth as we know it would not be possible without visible light and infrared radiation. This fact has led many to assume that there could not possibly be adverse health effects from frequencies below visible light and infrared EMFs.

Below the infrared is the radiofrequency (RF) portion of the spectrum, which includes microwaves and those frequencies used primarily for communication (AM and FM radio, television, cell phone, radar and all forms of "wireless" communication). The ability to tune in to a specific radio station is a function of the particular frequency at which that station broadcasts. Almost everyone is continuously bathed in RF radiation coming from radio and

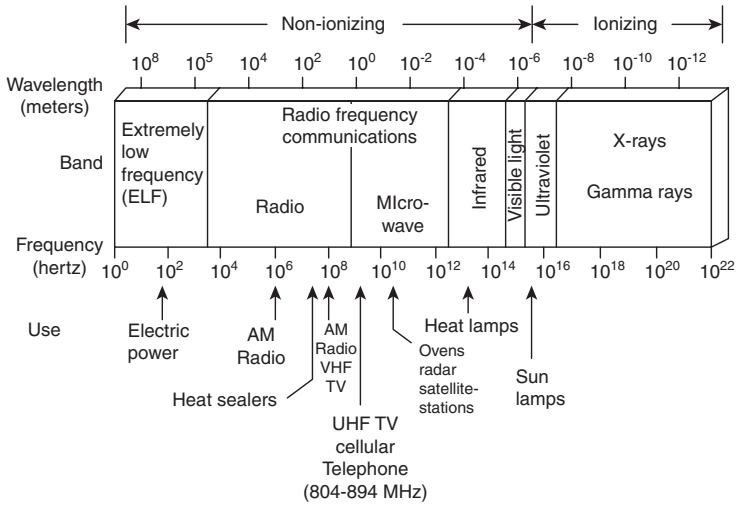

Figure 1 The electromagnetic spectrum.

television stations, cell towers and other communication and wireless sources, including satellites.

At the low end, there are electric and magnetic fields associated with electricity, and these are often called extra-low frequency electromagnetic fields (ELFs). Each of these is a vector, that is, it has a direction around its source. The electric and magnetic fields differ in other important aspects. The electric fields are a function of voltage, but are not related to current flow, while the magnetic field is a direct function of current. Both fall rapidly with distance from the source. All of us, unless we are totally removed from electricity, are exposed to these fields to various degrees over the course of our daily movements. They come from power lines, appliances, and even the wiring within our homes and offices. The extent of an individual's exposure depends on how close he or she is to these electric sources.

EMFs of lower frequency do not have sufficient energy to directly damage DNA, and are therefore identified as "non-ionizing" radiation. Since all EMFs are packets of energy, they do cause heating at sufficient levels, which is the basis of a microwave oven. The critical question is whether non-ionizing radiation at intensities that do not cause measurable heating pose any danger to human health. The health effect that has generated the most research is cancer. Both ELF and RF, however, have been reported to be associated with a great variety of biological and adverse health effects in addition to increasing the risk of cancer.

The current manuscript briefly reviews the evidence for this statement and the possible mechanisms whereby nonionizing radiation alters biological systems. More detailed information can be obtained from the Bioinitiative Report (www.bioinitiative.org) or by the textbook chapter by Carpenter (2).

Health effects of ELFs

The first indication that excessive exposure to EMFs from power lines was associated with an increase in risk of cancer came from the study by Wertheimer and Leeper (3), who reported elevations in childhood cancer among children living in homes near neighborhood power lines that carried high current, thus generating elevated magnetic fields. This study used "wire code configuration" as a surrogate measure of the magnetic field intensity rather than direct measurement. The principal factors were distance of the home from the power line and the thickness of the wire, since the utility was unlikely to use a thick, expensive copper wire to carry high current if a thin one would be sufficient. Wertheimer and Leeper (3) reported that children living in homes with high wire code configurations were more likely to develop cancer compared with those living in homes where the power lines were buried (i.e., where magnetic fields were low).

This report was greeted with skepticism, but the results were confirmed, at least for childhood leukemia, in many other studies around the world. There were three major meta-analyses of the associations between elevated magnetic fields in homes and childhood leukemia published in 2000 or earlier, all of which reported significant increases in rates of leukemia as magnetic fields increased (4–6). These meta-analyses reviewed and evaluated all reports prior to the time of publication, thus representing the state of the science at that time. If magnetic fields from power lines are associated with increased risk of cancer, then other sources of magnetic fields should have similar effects. Hatch et al. (7) reported significantly elevated rates of lymphoblastic leukemia in relation to the use of

electrical appliances during pregnancy and childhood. In a 1997 review by the US National Research Council (8), there was a statement that "The link between wire-code rating and childhood leukemia is statistically significant (unlikely to have arisen from chance) and is robust in the sense that eliminating any single study from the groups does not alter the conclusion that the associations exist". In 2002, the International Agency for Research on Cancer (9) identified ELF fields as being "possible human carcinogens". Later, the World Health Organization (WHO) (10) stated that "epidemiological data...show an association between ELF magnetic field exposure and an increased risk of childhood leukemia".

Reports since 2000 have generally confirmed an association between exposure to magnetic fields from power lines and childhood cancer. Draper et al. (11), for example, found that UK children living near high voltage power lines had a significantly elevated risk for leukemia but not other cancers, and that the risk decreased with distance from the power line. In a study from Japan, Kabuto et al. (12) found significant elevation in the risk of acute lymphoblastic leukemia [odds ratio (OR)=4.7; 95% confidence interval (CI)=1.15–19.0] among children whose bedrooms had magnetic fields >0.4 μT (4 mG), compared with those whose bedrooms had <0.1 μT. (An odds ratio is the ratio of disease found in the exposed population compared with those who are not exposed. Thus, an OR of 4.7 means that the risk of developing leukemia is almost five-fold greater in those with elevated bedroom magnetic fields. CI stands for confidence interval, and if the lower number is >1.0, epidemiologists consider that the relationship is statistically significant). In a study of 42 children with both leukemia and Down's Syndrome, compared with 117 Down's children who did not have leukemia, Mejia-Arangure et al. (13) reported an OR of 3.7 (1.05–13.1) for development of leukemia in children with Down's Syndrome exposed to magnetic fields ≥6 mG. Folliart et al. (14) and Svendsen et al. (15) found that survival after diagnosis of childhood leukemia was reduced among children with elevated magnetic field exposures. Kheifets et al. (16) performed a pooled analysis and concluded that "recent studies on magnetic fields and childhood leukemia do not alter the previous assessment that magnetic fields are possibly carcinogenic". Infante-Rivard and Deadman (17) reported that occupational exposure of a pregnant woman significantly increased the risk of her child developing leukemia.

Studies of adult leukemia in relation to residential exposure to magnetic fields have not shown strong associations, although Feychting et al. (18) studied adult leukemia in relation to both residential and occupational exposures. While neither showed significant results, when both sources of exposure were considered there was a significant elevated in risk of adult leukemia (OR=3.7; 1.5–9.4). In a meta-analysis of data published in 1997, Kheifets et al. (19) concluded that most studies showed a small overall increase in risk [risk ratio (RR)=1.18; 1.12–1.24]. Lowenthal et al. (20) reported that children living within 300 m of a power line had an elevated (but not statistically significant) risk of developing leukemia (OR=4.74; 0.98–22.9), while adults living within the same distance showed a smaller but significantly elevated risk (OR=3.23; 1.26–8.29).

Evidence for elevated risks of other diseases is less strong, although there is a building body of evidence for increased risk of Alzheimer's disease. A meta-analysis by Garcia et al. (21) concluded that there was a small but significant elevated risk in both case-control and cohort studies. Of interest was the observation by Feychting et al. (22) that amyotrophic lateral sclerosis (ALS) was also elevated in electrical occupations, but the risk appeared to be due to electric shocks rather than magnetic field exposures. Huss et al. (23), meanwhile, examined the risk of Alzheimer's disease in relation to residences near high voltage power lines and observed a dose-dependent increase in risk as a function of distance and duration of residence. However, they also found no association with ALS or Parkinson's Disease. There is one interesting report which showed significant elevations in rates of asthma in relation to magnetic field exposure during pregnancy (24), but this observation has yet to be confirmed in other studies. A variety of other adverse health effects have been reported but are less well documented (www.bioinitiative.org; 2).

However, in spite of the evidence cited above, many have questioned whether these associations are really reflective of a cause and effect, based primarily on two considerations. A single definitive mechanism, whereby these low energy EMFs can induce sufficient cellular changes resulting in cancer, has not been identified. There are many effects of EMFs that might explain the development of cancer, and many known human carcinogens, arsenic and dioxin for example, do not directly damage DNA. Several mechanisms have been suggested and demonstrated in some studies but not in others. DNA strand breaks have been demonstrated in neurons (25), but not in fibroblasts (26). Altered gene induction, especially of heat-shock proteins, has been reported (27), while other studies demonstrated alteration in cytokine production (28). Yang et al. (29) reported that children with a particular genetic variation in DNA repair genes are at greater risk of developing acute leukemia upon exposure to ELF. While any of these mechanisms can explain cancer development, none have been definitively linked to human disease.

Another reason some are skeptical is that most animal studies failed to demonstrate cancer as a result of magnetic field exposure (30). However, there is reason to question whether rodents are adequate models of human exposure to EMFs (2), since induced currents in small animals are very much smaller than those in a two-legged human. However, these considerations remain major sources of controversy in spite of the strong evidence in humans, which is the primary animal of interest.

Health effects of microwaves and other RF EMFs

There is a long history of reports of adverse health effects from exposure to RF. Much of the early work focused on concerns about radar. For example, Glaser (31) provided a bibliography of over 2000 publications on microwave and RF radiation effects up to 1971, many of which reported a variety of biological effects at intensities that cause tissue heating. Many of these publications were reviewed by McLees and Finch in 1973 (32). While they attributed most of the known effects of microwaves at that time to tissue heating, they also discussed the fact that many studies coming from the former Soviet and Eastern European countries reported non-thermal effects, and indeed set standards so as to avoid exposures below intensities that cause heating. Between 1953 and 1975, the Soviets irradiated the US Embassy in Moscow with microwaves at various intensities below the threshold for measureable tissue heating. There was no clear demonstration of increased mortality, but staff experienced more depression, irritability, difficulty in concentrating, and memory loss (33). This syndrome became known as the "microwave syndrome", which later came to be known as "electro-hypersensitivity."

There are a number of reports of effects observed with acute accidental exposure to RF. Williams and Webb (34) reported the experiences of two airmen exposed to high levels of RF radiation. After immediate sensation of heat, they later developed nausea, lightheadedness, and extreme apprehension with poor appetite and photosensitivity. Forman et al. (35) reported on two men who were accidentally and acutely exposed to microwave radiation. Both exhibited symptoms of headaches, insomnia, irritability, and emotional lability even after a 12-month follow-up. Both also developed hypertension several months after exposure. Schilling (36) reported on three men accidentally exposed to 785 MGz RF radiation. All experienced immediate sensations of heating, followed by pain, headache, numbness and parasthesia, malaise, diarrhea, and skin erythema. The first man, age 44, experienced lassitude, lack of stamina, drowsiness, and chronic headache. The symptoms gradually improved over a follow-up period of 3 years, but he still had chronic headaches by the third year. The second man, age 47, also had lassitude, lack of stamina, drowsiness, and chronic left sided frontoparietal headache, which was worsened by exposure to sun or heating. The symptoms improved somewhat over a follow-up period of 3 years, but the headaches remained. The third man, age 57, had a lower exposure and his symptoms almost disappeared after 18 months.

Meanwhile, Schilling (37) reported on six antenna engineers exposed in two separate incidents. All experienced acute headache, parasthesia, diarrhea, malaise, and lassitude. Four of the men showed no improvement in symptoms after follow-up for 3 or 4 years, with headache, loss of stamina, severe malaise, and lassitude being the major symptoms. Most of these exposures were at intensities that caused tissue heating. However these reports suggest that acute exposure to RF at intensities that cause tissue heating can, in some individuals, result in symptoms that last for years. Furthermore, it is striking how similar these symptoms are to those reported by electrosensitive subjects who usually do not have a history of some acute exposure.

Two things have happened in the past couple of decades. First, the Soviet Union collapsed and, with that, the threat and concern that they knew some hazards of microwave radiation that we in the West did not know about went away. Second, the variety and extent of useful RF has grown enormously thanks to innovative technology, clever marketing, and high consumer demand. As a consequence, most consumers have not been asking questions about safety. Until recently, there has been relatively little attention given to RF electromagnetic field exposures and human health. RF electromagnetic waves are those that are used for radio, television, radar, cell phones, smart meters, WiFi, and all forms of wireless communication. With the enormous increases in the use of cell phones, we now have a situation in which a very large segment of society is regularly exposed to high levels of RF. In addition, the whole population has increased exposure through the placement of cell phone towers, wireless buildings, and even wireless cities. In addition, smart meters also serve as the newest sources of RF radiation exposure.

The critical question today is whether or not RF and microwave radiation, which is ubiquitous in our everyday environment, can result in adverse human health effects. It is not surprising that intensities causing tissue heating

have biological effects. Most current RF exposures occur at intensities below that which results in measureable tissue heating, although new and more sensitive methods can demonstrate that even levels presumed to be non-thermal still cause heating (38). However, such exposure is everywhere and very few of the earth's inhabitants can escape from RF exposure from radio, television, radars, cell phone towers and use, smart meters, and WiFi. Satellites beam RF to earth, so even those who are living in the most undeveloped areas still receive greater RF exposure that those coming only from natural and cosmic sources. In light of such information, the most serious health concerns are discussed below.

Cancer

A major concern in relation to this topic is cancer. Balcer-Kubiczek and Harrison (39) reported years ago that microwave exposure increased malignant transformation of isolated cells in the presence of a tumor promoter. Repacholi et al. (40) demonstrated that lymphoma-prone mice exposed to 900 MHz EMFs showed enhanced probability of the development of cancer. Goldsmith (41) reviewed the associations between microwave exposure and cancer in humans and concluded that "RF exposures are potentially carcinogenic".

The strongest evidence for hazards from exposure to RF radiation has come from studies of individuals who have used a cell phone for prolonged periods of time. This evidence is reviewed in detail by Hardell and Carlberg (42) as a part of the proceedings of this meeting, and will only be briefly discussed here. Long-term use of a cell phone is associated with an elevated risk of brain tumors and acoustic neuromas, but only on the side of the head where the phone is regularly used. Acoustic neuroma is a benign tumor of the auditory nerve, but they, like other brain tumors, can be life-threatening because they occupy space and grow within the bony skull. In a meta-analysis, Hardell et al. (43) reported an OR of 2.0 (1.2–3.4) for glioma among adults who used a cell phone for 10 years or more, but only on the side of the head where the phone was used. There was also an OR of 2.4 (95% CI=1.1–5.3) for acoustic neuroma among long-term users. Risks for meningioma, another type of brain cancer, were elevated, but not significantly so. Kundi (44) reported on 33 epidemiological studies, and reported that the combined ORs from these studies showed an OR of 1.5 (95% CI=1.2–1.8) for glioma. There was also a non-significant elevation in ORs for acoustic neuroma, although there was no relationship with meningioma.

The INTERPHONE study was a 13-nation investigation coordinated by the WHO, and the first results were published in 2010 by The Interphone Study Group (45). While no excess risk of brain cancer was reported when comparing individuals who had ever used a cell phone to those who had not, there was more than a doubling of risk of brain gliomas in individuals who used a cell phone for 10 years or more, a 1.8-fold elevated risk if they used a cell phone for 1640 h or more, and a 1.3-fold elevated risk if they made more than 270 calls. The elevation in risk was only on the side of the head where the cell phone was regularly used. The Israeli component of this study found an elevated risk of ipsilateral parotid gland cancer with long-term cell phone use (46). The parotid gland is one of the salivary glands, but is located in the cheek, near to where a cell phone would be used.

There exists particular concern about risks to children exposed to RF. Hardell et al. (47) studied relative risks based on the age when a person was first diagnosed with a brain tumor. For use of either analog cell phones or cordless phones when assessed at >1 or >5 year latency, they found that individuals diagnosed in their 20s had higher ORs for brain cancer than those diagnosed at an older age. Later, Hardell et al. (48) reported that individuals whose first use of a cell phone was prior to the age of 20 years had an OR of developing glioma of 3.1 (1.4–6.7) using >1 year latency of cell phone use, while for all ages, the OR was 1.3 (1.1–1.6). The same relative relationship was observed with use of a cordless phone, where first use before the age of 20 years gave an OR of 2.6 (1.2–5.5), whereas for all ages, the OR was 1.3 (1.1–1.6). These studies support the conclusion that the use of cordless phones also increases risk, and that children are more vulnerable to risk of brain cancer than adults. The elevated risk to children poses a major concern given the current extensive use of cell phones, even by young children. It is important to note that children are also the ones who showed elevations in risk of developing leukemia among those living near high voltage transmission lines. These two kinds of studies clearly show that children are more at risk of developing cancer than adults when exposed to EMF radiation.

Older studies reported elevations in both leukemia and brain tumors among individuals with occupational exposures to RF (see www.bioinitiative.org for references), but the results were not very consistent across studies. Recent reports found elevated rates of leukemia among children who lived near AM radio transmitter sites (49–51). This is the same cancer elevated with exposure to power-line frequency EMFs, suggesting that leukemia is the cancer most likely to show elevated risk with whole body exposure to EMFs of any frequency.

The International Agency for Research on Cancer (52), a unit of the WHO, recently declared RF radiation to be a possible human carcinogen based primarily on the evidence that prolonged cell phone use increases risk of brain cancers.

Male fertility

There is increasing evidence that RF exposure has detrimental effects on male fertility. Agarwal et al. (53) reported that human sperm exposed to cell phone radiation showed a decrease in sperm motility and viability, and an increase in ROS. They speculated that men carrying a mobile phone in their trouser pocket may be negatively affected. In a separate report, Agarwal et al. (54) analyzed sperm samples from 361 men in relation to how many hours each used their mobile phone per day. They reported that sperm count, motility, and viability were reduced with increased use, and that abnormal morphology was increased with use. Wdowiak et al. (55) also reported that men using a mobile phone for longer periods of time showed more abnormal sperm morphology and reduced motility. Liu et al. (56) found that a mobile phone in global system for mobile communication (GSM)-talk mode resulted in ROS generation in mouse spermatocytes even at exposure levels that did not result in DNA strand breaks. De Jullis et al. (57) demonstrated mitochondrial ROS generation in human sperm, which led to DNA fragmentation after exposure to 1.8 GHz ranging from 0.4 to 27.5 W/kg. Rolland et al. (58) reported a significant and continuous 32.2% decline in sperm concentrations in 26,609 French men they examined between 1989 and 2005. While the report cannot deduce the cause, this was certainly the period of time characterized by a great expansion of RF exposure.

Electro-hypersensitivity (EHS)

This subject has been reviewed extensively by Havas (59) as part of the proceedings of this meeting. EHS will also be only briefly discussed here. The issue of EHS is controversial, with a significant number of individuals reporting that they are electrosensitive and often severely disabled (60). The symptoms are non-specific, including headache, fatigue, weakness, memory impairment, tinnitus, dizziness, irritability, heart palpitations, and other types of discomfort (61, 62). The difficulty is that most of the blinded studies that have been done under control conditions have not demonstrated that individuals who report that they are electrosensitive can tell when fields are on or not on (63). The exception is the report by McCarty et al. (64), which focused on an electrosensitive physician who reported headaches and temporal pain when exposed in a blinded fashion to EMFs. It is important that more careful studies of this syndrome be conducted in the future.

Effects on brain and behavior

Frey (65) reviewed studies up to 1965, primarily from former Soviet countries, and concluded that there were effects on the brain at low intensities of EMFs. There have been many studies on animal and human behavior in relation to exposure to RF, with somewhat inconsistent results. Huber et al. (66) reported changes in sleep EEG patterns in young males after a 30-min exposure to 900 MHz sEMFs (1 W/kg). Wiholm et al. (67) reported effects of 884 MHz signals on spatial memory performance in adults, and found that memory improved after exposure. Ellyahu et al. (68) reported that response time was reduced in humans exposed to 890 MHz RF. Barth et al. (69) conducted a meta-analysis on the neurobehavioral effects of GSM cell phones, and reported overall decreased reaction time, reduced working memory and an increase in errors, although the effects were small. Given reports that cell phone radiation results in alterations in cerebral blood flow (70) and changes in cerebral glucose metabolism (71), it is not surprising that there are neurobehavioral effects.

Presented evidence shows that pre- and post-natal exposure to cell phones increase behavioral problems in children (72). Aldad et al. (73) demonstrated that prenatal exposure of mice to cell phone frequencies results in hyperactivity and impaired memory, and that this is accompanied by altered synaptic transmission in the hippocampus, an area that is particularly important in learning and memory. These observations, if confirmed in future studies, have particular importance regarding prenatal and early life exposure of children, and have special relevance to RF exposure in schools where learning is supposed to take place.

Mechanisms by which RF EMFs cause non-thermal health effects

There have been a number of demonstrated actions of RF EMFs that can serve as bases for the various adverse health effects that have been documented (www.bioinitiative.org; 74). As discussed above, damage to sperm appears to

be secondary to ROS generation. Furthermore, ROS generation has been proven to lead to DNA damage and fragmentation. Garaj-Vrhovac et al. (75) examined peripheral blood from workers more or less exposed to marine radar EMFs, and demonstrated DNA damage by the comet assay. Exposed groups had significantly reduced glutathione and increased malondialdehyde, consistent with the conclusion that oxidative stress was the likely mechanism of the DNA damage. Luukkonen et al. (76) reported that continuous wave RFs, which did not produce ROS alone, significantly increased ROS generation generated by a chemical that has this action.

Gene induction has been reported in many but not all studies. Apoptotic and anti-apoptotic genes were found to have increased or decreased by between 7- and 11-fold in mouse brain cultures on exposure to 10.715 GHz RF, with a specific absorption rate of 0.725 W/kG (77). Zhao et al. (78) reported the up-regulation of apoptosis genes in response to GSM cell phones, with the up-regulation being greater in cultured neurons than astrocytes. However, Sakurai et al. (79) reported no effect of cell phone frequencies on gene expression in a human-derived glial cell line. Yan et al. (80) reported the up-regulation of specific mRNAs in rat brains after exposure to cell phone frequencies of 6 h/day for 126 days. Luo et al. (81) conducted a proteomic analysis of protein expression in early stage placental villous in women prior to undergoing pregnancy termination. The women were sham or exposed to 1.6 to 8.8 W/kg from a commercial cell phone placed on the abdomen. On two-dimensional electrophoresis, up to 15 spots showed significant change of at least 2- to 2.5-fold. Gerner et al. (82) used a sensitive proteome analysis to study changes induced in cultured human cells in response to short-term RFs similar to those from a cell phone. They found significant increases in protein synthesis in Jurkat T-cells and fibroblasts, but less in activated primary human monocuclear cells, and no response in quiescent cells (82).

DNA damage has also been reported at non-thermal intensities of RF exposure. Ruediger (83) reviewed 101 publications, and found that 49 reported genotoxic effects while 42 did not; of these, 8 reported no direct effect of RF but an enhancement of the genotoxic action of chemicals. Tice et al. (84) reported that cell phone RF caused significant DNA and chromosomal damage, which they assessed by micronuclei formation, in human cultured lymphocytes. They found that the degree of damage varied with specific absorption rate and exposure duration, but did not find significant effects on leukocytes. Diem et al. (85) found single and double-strand breaks by the comet assay upon exposure of cultured rat fibroblast and granulosa cells to 1800 MHz RF. DNA damage secondary to 1800 Hz RF was studied by Xu et al. (86) using six different cell types, and found that not all cell types were equally sensitive. Markova et al. (87) reported that stem cells were more sensitive to microwave from cell phones than differentiated cells. Hoyto et al. (88) found that ornithine decarboxylase activity was altered in primary astrocytes, but not in secondary cell lines, after exposure to 872 MHz RF radiation. These observations are important because some previous studies (89, 90) discredited gene toxicity studies of RF based on the observation that the aforementioned studies lack consistent results. However, the lack of effect on some cells may be as real as the adverse effects on other types of cells.

Together, the abovementioned results suggest that various cell types react quite differently to RF exposure and that sensitivity varies with the degree of cell activation. More studies are thus needed to determine whether there are real differences in cellular sensitivities.

Characteristics of EMFs responsible for adverse health effects

It is striking that the cancers associated with exposure to ELFs (primarily leukemia, some brain cancers) and RF (primarily brain cancer, some forms of leukemia) are so similar when the energy of the EMFs are so different. This has led many researchers to suggest that EMFs may have other hazardous components apart from pure sine wave. There are transients, harmonics, pulses, and carrier and resonance frequencies that complicate real-life exposures. Vignati and Giuliani (91) reported RF associated with high-voltage power lines. Others (92) related adverse health effects to “dirty electricity”, i.e., multiple transients, harmonics, and peaks of magnetic fields that are commonly found superimposed on the 50 or 60 Hz signal. Given that these transients are present in virtually all electrical sources, it becomes very difficult to sort out which particular component of the wave forms is most closely associated with adverse health outcomes.

The same concerns apply to RF. Markova et al. (93) investigated the effects of cell phone microwaves on measures of stress responses and genotoxic effects on human lymphocytes, and found that the degree of damage varied depending on the function of the carrier frequency. Many of the uses of RFs involve pulses of high intensity but of short duration. This is the case with smart meters. However, peak pulse amplitude may be of greater significance than aggregate exposure over time. Further research on these issues is needed. However, it is almost impossible to do

this study in humans because long-term exposures cannot be controlled and the latency for the diseases of concern is very long. Unfortunately, there is no satisfactory animal or cellular model that can be used to date.

Specific sources of exposure to RF EMFs

Cell (mobile) phones

The major concern about cell phones is that they are usually held close to the head, resulting in significant exposure to the brain and other tissues on the side of the head where the phone is usually placed. This problem is easily avoided, however, by use of a wired ear piece or a speaker. Although no study has yet to be conducted on this issue, there is also growing concern about cell phones in the "on" mode being held in belts or pockets, thus exposing the abdomen to harmful RF EMF. Texting, however, is not yet a major concern, since there is no evidence yet of cancer developing in the fingers.

There are a number of relatively simple steps that individuals can take to reduce their exposure to RF from cell phones. First, a landline should be used whenever possible because wired phones do not generate RF. Second, cell phones should not be held directly to the ear. Rather, a wired ear piece can be used, thus keeping the phone off the body. The RF from a cell phone falls off rapidly with distance, so a phone on the desk with a wired earpiece will not result in a high exposure. Third, users should not wear an active phone on any part of the body, including pockets or belts. The phone should be kept in a briefcase or a pocketbook. Fourth, users should also not sleep with a phone under the pillow. Fifth, the use of Bluetooth does reduce but not eliminate exposure to the head, but using it while wearing the phone on your belt only changes the parts of the body that is exposed. Children, in particular, should not use cell phones held to the ear. If it is considered necessary for a child to have a cell phone, they should be given clear instruction that it is to be used only in emergencies. Table 1 provides estimates of relative exposures coming from the use of a cell phone compared with other sources.

Table 1 RF Exposure from various sources.

Cell phone (Maximum power at ear)	5000 $\mu W/cm^2$
Cell phone (1% duty per day at ear)	50 $\mu W/cm^2$
Cell phone (1% duty per day whole body)	0.75 $\mu W/cm^2$
Cell tower (Maximal exposure 60 m from school)	0.83 $\mu W/cm^2$
Typical smart meter (peak power at 20 cm)	227 $\mu W/cm^2$
Typical smart meter (peak power at 3.1 feet)	10 $\mu W/cm^2$
Typical smart meter (peak power at 5.7 feet)	3 $\mu W/cm^2$
Typical smart meter (5% duty cycle at 20 cm	11 $\mu W/cm^2$
Typical smart meter (5% duty cycle at 3 feet)	0.545 $\mu W/cm^2$
Zigbee radio (peak power at 20 cm)	31 $\mu W/cm^2$
Zigbee radio (50% duty cycle at 3 feet)	0.74 $\mu W/cm^2$
WiFi Router (100 mW maximal power at 3 feet)	1 $\mu W/cm^2$

Source: Karl Maret, personal communication, "duty cycle" is the percent of the day a person is exposed, 1 foot is equal to 30.4 cm.

Smart meters

Wireless smart meters use RF radiation to communicate household or office electrical usage to the utility. However they usually produce atypical, relatively potent, and short-pulsed RF microwaves whose biological effects have never been fully tested and may, in fact, be more hazardous than other waveforms. The California Pacific Gas and Electric acknowledged to the state Public Utilities Commission (94) that it emits millisecond-long RF bursts about 9600 times a day, on average, with a maximum of 190,000 daily transmissions and a peak level emission that is two and a half times higher than the stated safety signal. It is likely that most other smart meters are similar. The power density from a smart meter is in the same range as that from a cell phone used at a distance from a cell tower. However, the intensity of exposure in the immediate environment is, under most circumstances, lower than what one gets from holding a cell phone close to one's head. This is because one does not hold the smart meter close to one's head. The difference between a cell phone and a smart meter environment is that while the cell phone is used only intermittently, a smart meter generates RF continuously, with intermittent pulses that can expose the whole body of a person near it.

To my knowledge, there have been no studies on the health effects of smart meters because these are relatively new devices. In their current use, smart meters only transmit information from a home or office to the utility on the total electrical usage with time. However, this is just the tip of the iceberg in relation to what is planned. Appliance makers are currently placing Zigbee RF transmitters in electrical appliances, and the plan is that every appliance is designed to have such transmitters that can communicate to the smart meter. In turn, the smart meters will communicate to the utility companies some information pertaining to the electrical usage of that particular appliance. Utilities insist that this will help homeowners know how much electricity their equipment utilizes.

For example, a user will know how much energy the clothes dryer requires, and that rates can be set such that the user can dry clothes at 3 AM when usage is low, with corresponding lower prices. Such technological adjustments can make kitchens and laundry rooms hotbeds of RF generation above and beyond what comes from the smart meter. While it is true that the nature of exposure to RF from smart meters and Zigbee generators may not be significantly different from that coming from other wireless devices, what is important is cumulative, aggregate exposure. Smart meters and Zigbee transmitters can add significantly to aggregate RF exposure.

The installation of smart meters and the technologies associated with them have also raised concerns about privacy (95). Utilities will have full access to personal data, ultimately including the use of each individual appliance. As cited in this article "Detailed electricity usage data offers a window into the lives of people inside of a home by revealing what individual appliances they are using, and the transmission of the data potentially subjects this information to interception or theft by unauthorized third parties or hackers".

WiFi

WiFi deploys pulse-modulated microwave radiation (within the larger RF radiation spectrum) with a carrier frequency that is similar to that used by a microwave oven (about 2.45 GHz). The pulse-modulation of a wave with lower frequencies, in addition to the high-frequency carrier signal, increases the exposure complexity and, in turn, the possible health effects in an exposed population. WiFi constantly exposes building occupants, including children and adults, from both computers and infrastructure antennas. The duration may be a more important contributing factor to RF radiation effects than exposure levels. While intensities are low under most circumstances, places such as computer laboratories with many wireless devices can result in significance intensities of RF. Thus, while not uniquely harmful WiFi increases aggregate RF exposure. The problem, however, is much greater when using a wireless laptop computer, primarily because if held on the lap it will involve significant exposure to reproductive and other abdominal organs.

Khalid et al. (96) measured RF levels coming from wireless local area networks (WLAN) in schools and calculated the time-averaged power density from a laptop to be 220 $\mu W/m^2$ at 0.5 m and the peak SAR at the torso of a 10-year old child at 34 cm to be 80 $\mu W/kg$. Findlay and Dimbylow (97) calculated that a 10-year old child sitting next to a wireless computer would get <1% of the SAR calculated for the head of a typical cell phone exposure. However, exposure can increase in a WLAN environment, in which multiple devices are used (98).

Cell and radio transmission towers

RF exposures from GSM cell phone towers can be significant. Haumann et al. (99) reported that cell towers dominated FM or TV emissions, and can exceed 1000 $\mu W/m^2$, suggested to be the average threshold for non-thermal effects. At a typical residential distance of 250 m in a direct line of sight, the observed levels were approximately 200 $\mu W/m^2$. Frei et al. (100) monitored mean weekly exposure to all forms of RF in 166 residents of Basel, Switzerland, and found that cell phone base stations were the largest sources of exposure (32.0%), followed by cell phone handsets (29.1%), and digital enhanced cordless telecommunication (DECT) phones (22.7%). Thus, cell towers may be a very significant source of exposure.

Others

There are many other sources of RF in our environment, although most are of minor importance in the general population relative to those sources discussed above. RF leaking from microwave ovens can be easily avoided by stepping away when the oven is being used. There are many satellite sources of RF, although of low intensity. There are also many person-to-person communication devices that can result in significant exposure to the users.

Standards and regulation of EMFs

There are major differences in national and international standards for EMF exposures. Many countries accept the standards proposed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) (101), a non-governmental organization with members appointed by the organization. Different countries and organizations set standards for specific frequencies and duration of exposures. Different exposure standards are also often set for the general public and for occupational exposures. ICNIRP states the scientific rationale for standard setting is based on the following:

A. Between 1 Hz and 10 MHz, basic restrictions are provided on current density to prevent effects on nervous system functions;
B. Between 100 kHz and 10 GHz, basic restrictions on SAR are provided to prevent whole-body heat stress and excessive localized tissue heating; in the 100 kHz to 10 MHz range, restrictions are provided on both current density and specific absorption rate (SAR);
C. Between 10 and 300 GHz, basic restrictions are provided on power density to prevent excessive heating in tissue at or near the body surface.

These recommended restrictions are basically designed to prevent electrocution and cooking. They do not acknowledge any effects that are not due to either current or tissue heating. Table 2 lists standards for 900 MHz RF in different countries at some frequencies compared with the recommendation coming from the Bioinitiative Report. Different countries and organizations set standards for specific frequencies and duration of exposures. Standards similar to those from ICNIRP apply in Australia and New Zealand (102).

It is clear that there is a great lack of consensus regarding appropriate safety standards for EMFs. One major barrier is the belief of those coming primarily from the physics and engineering communities that there EMFs have no biological effects other than those caused by tissue heating. This belief ignores and denies all of the evidence presented above, and the resulting standards fail to protect the health of the public.

One major concern with the recommendations of the ICNIRP and those of most governmental agencies is the influence of conflicts of interest in the setting of standards, the interpretation of research findings, and the overall integrity of the process. Huss et al. (103) reported that the source of funding for studies on health effects from cell phone use dramatically influenced the reported results, in that industry-funded compared with publicly-funded studies were the least likely to report a statistically significant adverse effect. This concern about conflicts of interest applies to many public health issues, including those of fracking and food, as discussed in other papers from this meeting. A study design and interpretation of its results may be influenced by the prejudices of investigators and funding organizations; furthermore, money for politicians, lobbyists and advertising can sway opinions and governmental actions in a way that is not consistent with objective science.

Table 2 RF exposure limit recommendations for the general public by different organizations or countries and exposure from various RF devices.

International Commission on Non-Ionizing Radiation Protection	600 $\mu W/cm^2$
US Federal Communications Commission	600 $\mu W/cm^2$
Health Canada	600 $\mu W/cm^2$
Greece	300 $\mu W/cm^2$
Belgium	112.5 $\mu W/cm^2$
Italy	100 $\mu W/cm^2$
Israel	45 $\mu W/cm^2$
China	40 $\mu W/cm^2$
Russia	10 $\mu W/cm^2$
Poland	10 $\mu W/cm^2$
Bioinitiative Report (Outdoor) 2007	0.1 $\mu W/cm^2$
Bioinitiative Report (Indoor) 2007	0.01 $\mu W/cm^2$

Source: Karl Maret, personal communication.

The cost of doing nothing

At present, we do not know precisely the degree to which the risk of cancer and other adverse health effects are increased by exposure to RF fields from cell phones, smart meters, and other wireless devices. Human studies are difficult under any circumstances, but these difficulties are even greater when studying the effects of ELF and RF EMFs. Levels of exposure to EMF fields vary over the course of every day as we move through our environment, use appliances or cell phones, as well as sit or stand near smart meters and other wireless devices for varying periods of time. There is whole body exposure from cell phone towers, radio and television transmission towers, and WiFi. Most studies, to date, have relied on the place of residence in relation to power lines or cell towers or self-reports of how frequently individuals used their cell phones 10 years ago. This is difficult to remember with any certainty. Thus, exposure assessment in almost all EMF studies is extremely poor. Given the long latency for development of cancer and other chronic diseases, one would expect that the true risk of disease is significantly greater than that reported when exposure is not accurately measured, and yet a statistically significant association is found, compared with a study in which it were possible to accurately monitor all exposure.

There is considerable evidence that children are more vulnerable to many environmental insults than adults (104). The reality is that children are using cell phones at increasing rates and for long durations. Therefore, if the risks are real, and especially if children are more susceptible, we may be facing an epidemic of brain and other cancers, especially leukemia. The concern is increased because, to date, there has been little warning advising restrictions on use of cell phones, especially by

children. While questions regarding mechanisms are not all answered, the evidence for a relationship between cell phone exposure and cancer is sufficiently strong so as to demand action. The alternative may be significant increases in certain cancers. It is not clear whether there is increased risk of all kinds of cancer following exposure, because there has not been a study of, for example, the health hazard of wearing a cell phone on your belt and pelvic cancers.

A newly published review of neurological disorders and deaths in the Western countries (105) found that between 1997 and 2010, there was a sharp rise in dementia and other neurological deaths in people under 74 years, with earlier onset affecting people under 55 years of age. Of the 10 biggest Western countries, the USA had the worst increase in all neurological deaths: 66% for men and 92% for women. The authors speculated that these changes could be attributable to the many environmental and social changes over the past 30 years: "The explosion in electronic devices, rises in background non-ionizing radiation – PC's, micro waves, TV's, mobile phones; road and air transport up 4-fold increasing background petrochemical pollution; chemical additives to food etc. There is no one factor, rather the likely interaction between all these environmental triggers".

Recently, the Board of the American Academy of Environmental Medicine (106), in opposition to installation of wireless smart meters, stated "Chronic exposure to wireless RF radiation is a preventable environmental hazard that is sufficiently well documented to warrant immediate preventative public health action", and called for "An immediate moratorium on 'smart meter' installation until these serious public health issues are resolved. Continuing with their installation would be extremely irresponsible". The American Academy of Pediatrics, in a letter to a US Congressman (107), stated that "Children are disproportionately affected by environmental exposures, including cell phone radiation. The differences in bone density and the amount of fluid in the child's brain compared to an adult's brain could allow children to absorb greater quantities of RF energy deeper into their brains than adults. It is essential that any new standards for cell phones or other wireless devices be based on protecting the youngest and most vulnerable populations to ensure they are safeguarded through their lifetimes".

We would be wise to follow this advice from the physician organizations most responsible for dealing with human disease as a result of environmental exposures. There is now greater evidence of the risks posed by EMFs on human health, affecting billions of people worldwide. The status quo is not acceptable in light of the evidence for harm. Many scientists and medical experts urgently recommend that measures following the Precautionary Principle be applied immediately – such as using landlines and wired laptops and smart meters – to reduce biologically inappropriate microwave exposure. We are not advocating the abolishment of RF technologies, only the use of common sense and the development and implementation of best practices in using these technologies so as to reduce exposure and risk of health hazards.

In summary, current extensive evidence shows that exposure to excessive levels of ELF and RF EMFs results in elevated rates of cancer and some other diseases, and such evidence is rapidly growing. The risk is greater for children, who are the most vulnerable members of our society and those on whom our future is most dependent. Thus, we need to find ways in which to use contemporary technology safely and learn to balance risks against benefits.

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