50-60 Hz magnetic fields and cancer, forty years of research: it is time to reassure

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In 1979, an epidemiological study carried out in Denver, Colorado first suggested that very weak alternating magnetic fields arising from electrical lines around houses was associated with an increased risk of cancer in children. The potential impact on public health was high, considering the fact that exposure to power-frequency magnetic fields is omnipresent. All power transmission and distribution networks, domestic and industrial wiring, and all kinds of electrical equipment give off magnetic fields. The hypothesis was taken seriously and substantial research budgets have been devoted not only to answering the important question raised by this study but more broadly to identify all other potential health effects of magnetic fields. Since 1979, an exceptional number of scientific studies have been published worldwide. In 2007, the World Health Organization published one of the most comprehensive review so far. The present article summarizes important facts regarding the interaction between a magnetic field and the human body and the key findings from this extensive research looking for a possible link with cancer.

Static fields	**+50/60 Hz alternating fields**
Earth natural MF = 25 to 65 μT	Average MF from electricity in homes = 0,05 - 0,5 μT
Suggested limit for cardiac implants = 500 μT	Typical worker exposure = 1 – 1,000 μT
Typical household fridge magnet = 5,000 μT	Suggested limit for cardiac implants = 100 μT
Recommended limit for the general public = 400 000 μT	Recommended limit for the general public = 200 μT
Recommended limit for workers = 2 T	Recommended limit for workers = 1,000 μT
MF inside a MRI (magnetic resonance imaging) = 1 - 3 T	First known effect (magnetophosphenes) in humans = 15,000 μT
Human body tolerance = 8 - 10 T	Human body tolerance > 100,000 μT

Magnetic fields : some references
1 tesla (T) = 1,000,000 microteslas (μT)

Magnetic fields and the human body

The intensity of the earth's natural static magnetic field to which everyone is exposed is about 50 microteslas (μT). It varies from 25 μT at the equator to 65 μT close to the poles. Unlike many species, humans lack any specialized organs to detect the natural magnetic field. The human body is more or less transparent to the magnetic field and can tolerate static fields up to a few teslas (one tesla equals 1,000,000 μT) without any adverse effects. Magnetic resonance imaging requires such fields. They are well tolerated and are not known to induce any particular acute or chronic damage to tissues.

In homes, the use of electricity produces magnetic fields but at much lower levels, typically between 0.05 to 0.5 μT, a few hundred times weaker than the earth's natural field. However, since the current flowing in wires is an alternating current, the magnetic field changes direction constantly, at a frequency of 60 or 50 cycles per second (60 or 50 Hz) depending on the country. The oscillating nature of magnetic fields induces voltages and currents in conductors. Computations based on anatomical models have shown that voltages induced in the brain and the heart tissue by a typical residential ambient field of

0.1 μT magnetic field at 60 Hz is in the order of 0.001 mV/m. From a biological point of view, this is an extremely weak voltage.

The first effect known to occur in humans appears at induced voltages of about 100 to 200 mV/m [1], an intensity which is five orders of magnitude higher than the induced field at 0.1 μT, corresponding to magnetic field levels of 10,000 to 15,000 μT. It appears in the form of a faint flickering visual sensation called magnetophosphenes. This effect results from altering neurons activity in the retina of the eye. The phenomenon is considered harmless and occurs occasionally during magnetic resonance imaging procedures. The threshold needed to provoke a direct nerve stimulation is much higher at around 5 V/m.

Clearly, from both, a physical and a biophysical point of view, it is not reasonable to expect any particular biological effect to occur at typical residential magnetic field levels.

What triggered the idea that residential magnetic fields would increase the risk of cancer?

Humans have been exposed to alternating magnetic fields ever since electricity became common use more than a century ago. Over that period of time, there has been no anecdotal evidence or scientific evidence of any kind suggesting that magnetic fields at home or in the workplace could be detrimental to human health and certainly no suggestion that they could be carcinogenic. In particular, health surveillance programs of electrical workers chronically exposed to magnetic fields of much higher intensity (up to 1,000 μT) did not reveal any harmful effects.

Unlike most carcinogens, the hypothesis that magnetic fields could be a human carcinogen was not triggered by an unusually high incidence of a particular cancer among a group of individuals exposed to high fields. Neither was it suspected on the basis of any scientific observations from experimental studies or biophysical considerations. The hypothesis was generated by a so-called "hypothesis generating" epidemiological study carried out in Denver, Colorado in 1979 [2]. The authors were looking for possible environmental factors around the homes of children who had cancer. They reported a statistically significant association between the presence of a dense electrical network around houses and the risk of various childhood cancers including leukemia. The magnetic field produced in houses by the current flowing in the wires was estimated to be about 0.2 μT and the authors suggested it might be the reason for this association.

The design of the original Denver study was exploratory by

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nature and subject to many possible sources of error, a common situation with epidemiological studies.

Despite the scepticism, the study was given very serious consideration and led to a vast international research effort including state of the art procedures for testing carcinogenicity.

Key findings regarding carcinogenicity

1. No evidence of general carcinogenicity

Magnetic fields penetrate the body easily without any significant distortion and are not weakened by the presence of biological tissues. Consequently, all tissues and cells of the body are exposed to the same magnetic field level. If 50/60 Hz magnetic fields were a carcinogen, we should expect an increased incidence of cancer for a majority of tissues and cell lines, much like it is observed with penetrating ionizing radiation like gamma rays and X rays. The control mechanisms of cell differentiation and proliferation that prevent the transformation of a normal cell into a cancer cell are very similar across cell lines and across species [3]. Generally, if a carcinogen reaches a particular tissue and creates sufficient damage to these control mechanisms, cancer risk increases in that tissue.

More than 200 epidemiological studies have been published on the possible association between magnetic fields and various cancers. Most epidemiological studies were carried out among exposed workers where average fields are up to 20 times the residential exposure with short exposure periods up to 1,000 times the residential exposure level. All common types of cancer have been examined.

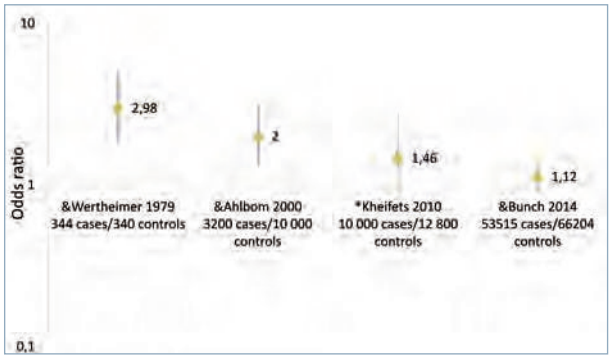
Those studies failed to show an increased risk of cancer. One of the largest study – if not the largest - carried out among a collection of over than 225,000 electrical utility workers looked at past exposure to magnetic and electric fields of 4,154 cases of cancer [4]. The cancer risk (all types of cancer) among the highest exposed group was no different from the lowest exposed group. Other studies compared cancer mortality rates of exposed workers of electrical utilities from various countries including United States, Canada, France and United Kingdom to the general public cancer mortality rates.

Results consistently showed cancer rates 20 to 30 percent lower among workers, a normal observation known as the "healthy worker effect".

2. No confirmation of the original findings

About 40 epidemiological studies using more sophisticated methodology have tried to replicate the original observation. Instead of relying on the mere presence of electrical lines around the house, magnetic fields were actually measured inside the homes, sometimes in the child's bedroom or directly with a dosimeter worn by the child for 48 hours. The largest studies carried out in United States, Canada and United Kingdom failed to show a clear association between the measured magnetic field and childhood leukemia. These studies also tried to replicate the original finding by using the same approach based on the description of the electrical lines around the house. No association was found. Then, epidemiologists attempted to pool available study results. By transforming the original data to make them more comparable, a statistically significant association between childhood leukemia and exposure to field levels above 0.4 µT was reported in 2001 [5]. However, an updated pooling was published in 2010 which included new studies [6]. The association was weaker and was no longer statistically significant.

In 2014, an exceptionally large study carried out in England showed that the association between the presence of a high voltage transmission lines and childhood leukemia observed in the 1960-70s was no longer present after the 1980s. The authors concluded that past observations of associations between the presence of powerlines and childhood leukemia almost certainly cannot be attributed to powerline-generated magnetic fields but most likely to the evolving population characteristics of people living near powerlines.



1979 – 2014 Progressive decrease of the association between childhood leukemia and 50/60 Hz magnetic fields as the epidemiological study methodology improved and the statistical power of the studies increased. The Wertheimer study was the first study which alerted the scientific community in 1979. Ahlbom was the first meta-analysis combining studies published between 1993 and 1999. Kheifets is another meta-analysis which included studies published after 2000. Bunch is the last large-scale study published available at the time of the writing of the present article.

In summary, not only did the search for a carcinogenic effect in various tissues fail but the evidence for an association with childhood cancer weakened considerably after conducting more sophisticated and larger studies.

3. No carcinogenicity in animals.

Human beings are mammals and their respective physiology is very similar. It is no surprise that among the hundred or so human carcinogens confirmed so far, all of them, with no exception, have been shown to be carcinogenic to animals. For physical agents like ultraviolet light or ionizing radiation, extrapolation from animals to humans has been shown to be more reliable than for chemicals. Indeed, the damage to the cell is the same and does not depend on potential metabolic differences between species that sometimes occur with chemicals. For a physical agent, we should also expect that the dose at which an eventual carcinogenic effect is observed in animals is generally comparable to the dose producing a carcinogenic effect in humans.

Magnetic field carcinogenicity has been extensively tested on animals. Long term animal studies were carried out using standard protocols (National Toxicology Program) with rats and mice. Some studies have been replicated in different laboratories around the world. Animals were exposed typically for two years, about 20 hours per day. The highest exposure group varied from 1,000 to 5,000 µT. These unusually high exposure levels did not cause any signs of general toxicity. Up to 50 organs have been examined for the presence of tumors.

Results are highly consistent: overall, no evidence of an increase in the incidence of benign or malignant tumours including leukemia was reported. •••

Another hypothesis put forward is that magnetic fields do not increase the incidence of cancer themselves, but rather modify the effect of another carcinogen. Over 20 animal studies have been carried out so far to test this hypothesis, subjecting animals to a known carcinogen and then to magnetic fields. As a whole, the results are negative.

Considering the very high sensitivity (the ability to detect an effect if it is present) of long term animal studies, the absence of any carcinogenic effects constitutes strong evidence against carcinogenicity in humans. It is particularly compelling since testing was done at field levels many thousands times higher than typical residential field.

4. No signs of general toxicity at very high level

Carcinogenicity is only one of many aspects of the toxicity of a particular chemical or physical agent. Carcinogens also cause an array of chronic or acute pathologies at similar doses. For example, solar irradiation causes skin cancer but also causes burns, premature aging of the skin and photosensitization. Cigarette smoking causes cancer but also chronic bronchitis, vascular and heart diseases. Asbestos causes cancer but also pulmonary fibrosis.

Hundreds of studies were conducted on animals. No signs of general of specific toxicity have been reported in animals chronically exposed for two years from a few weeks of age to field levels up to 5,000 μT (50,000 times higher than the average residential level). Some studies included exposure during perinatal and juvenile exposure. Comparisons of group mean body weights and body weight gains demonstrated no significant differences between any group exposed to magnetic fields and the controls. No signs of stress and no difference in behaviour were noted between the exposure groups.

A few experimental studies have been carried out on human volunteers at high field levels (100 to 3,000 μT). The subjects were not able to perceive the presence of the fields, no adverse effects nor signs of toxicity were reported.

Thus, the absence of any toxicity at levels up to 50,000 times the average field in homes (0.1 μT) makes a carcinogenic effect extremely unlikely.

5. Absence of a plausible biological mechanism.

As with all known carcinogens, if magnetic fields were carcinogenic to humans, we should expect to detect some of the primary or elemental damage to the cells that led to the transformation of a normal cell into a cancer cell. Over the years, many short term tests have been developed for carcinogenicity testing. Most of them look for signs of genotoxicity, a common step before a carcinogenic transformation.

Despite hundreds of in vitro and in vivo experiments, no physiological effect nor damage has been identified at field levels typical of residential (0.1 μT) or occupational exposure (a few μT). Physicists have explored by theoretical studies and experimental work many potential fundamental mechanisms of interaction between magnetic field and matter and none of these mechanisms have been deemed to be operational to a significant extent at environmental levels.

6. No clear evidence of any adverse health effects

In 2007, the World Health Organization published an extensive review presenting and summarizing all relevant epidemiological and toxicological studies available at the time. Possible health effects were examined for each of the following categories: neurobehavior; neuroendocrine system; neurodegenerative disorder; cardiovascular disorders; immune systems and haematology; reproduction and development and cancer [1].

Overall, no consistent adverse findings were identified and no particular health effect has been reported as likely to occur at field levels below the current exposure limits recommend by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). These limits are 200 μT for the public and 1,000 μT for the workers.

Conclusions

The amount of data generated by this international research effort is exceptional. Independent experimental lines of evidence from the physics, the biology and the toxicology, failed to support the hypothesis raised by the 1979 epidemiological study. Large and sophisticated epidemiological studies failed to confirm the original finding.

Cancer is not a statistical or mathematical abstraction. If power frequency magnetic fields were a carcinogen, they would have to damage significantly the cell division process of lymphocyte precursors in the bone marrow of children and it would have to do so at extremely low field levels (under 1 μT) and spare all other tissues. Magnetic fields would have to do that by an unknown mechanism, leaving no discernible effect at the cell level and without inducing any other pathology even at doses tens of thousand times higher. It would be the first human carcinogen not to show a similar effect in animals. It would be the first carcinogen to act exclusively in children. It would also be the first carcinogen for which the effect decreases with intensity and duration of exposure since no evidence of carcinogenicity have been identified among exposed workers.

Clearly, those assumptions are not reasonable. We can safely assume that the hypothesis raised by the Denver study in 1979 is very likely to be a false alarm, a situation which is not uncommon with exploratory epidemiological studies. The exceptional amount of data accumulated over the last 35 years confirms what common sense would have suggested: power-frequency residential magnetic field levels are much too weak to influence human biology. Recommending preventive or precautionary measures is not justified. It would do more harm than good. It is time to be reasonable and reassure the public.

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