

Pediatric Health Effects of Chronic Exposure to Extremely Low Frequency Electromagnetic Fields

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Abstract: Extremely low frequency electromagnetic radiation (ELF-EMR) is an omnipresent component of electricity, with a frequency of 3-30Hz, and wavelengths 3,450-5,996km long. We reviewed the scientific literature regarding pediatric health effects resulting from chronic exposure to ELF-EMR and compared these with the international safety standards. Articles published between 1980-2007 were identified using Medline, Cancerlite, Science Citation Index, and EMBASE.

For the general population, the International Commission on Non-Ionizing Radiation Protection considers chronic exposure to magnetic fields lower than 100 μ T to be safe. However, even 0.3-0.4 μ T has been associated with an increased risk of acute lymphoblastic leukemia (ALL) in children. Although there is no experimental model to test the effects of ELF-EMR on organic systems, the Precautionary Principle is fundamental to the protection of children who are exposed to residential radiation doses higher than 0.3 μ T.

Keywords: Children, environmental risk, policies, electromagnetic fields, power lines.

KEY POINTS

1. In industrialized countries, most homes are exposed to average magnetic densities produced by the electrical energy of less than 0.1 μ T.
2. The International Commission on Non-Ionizing Radiation Protection considers chronic exposure levels lower than 100 μ T as safe levels of exposure for the general population. However, the average residential exposure to magnetic field densities is \geq 0.3-0.4 μ T and has been associated with an increased risk for developing childhood ALL.
3. The application of the Precautionary Principle is essential and strongly prudent for all children who are exposed to residential radiation doses \geq 0.3 μ T.

INTRODUCTION

Naturally occurring electromagnetic fields surround all living organisms on earth. In addition, when electricity is

conducted through power lines, both electric and magnetic fields are generated in the vicinity of the power lines and appliances. ELF-EMR comprises of very long wavelengths and is part of the electromagnetic spectrum (Fig. 1), a component of electricity omnipresent in western countries.

The demand for electrical energy has made its generation, transfer, and distribution through electrical power lines of high voltage (ELHV) essential. Electrical powerlines, generate electrical and magnetic fields that oscillate at 50 or 60 Hz [1]. The electrical fields generated around two objects of different potentials (voltages) are measured in units of volts per meter (V/m) or kilovolts per meter (kV/m). The magnetic fields, generated around a conductive cable, depend on the current in the cable and the distance to the cable, and are expressed in Tesla (T) or Gauss (G) units. When these are associated with ELF electrical energy (frequencies 50 Hz and 60 Hz), they are expressed in units of microtesla (μ T).

SIGNIFICANCE

Given the increased concern and focus on pediatric environmental health in recent years, it is necessary to address new and emergent clinical issues. Increasingly, parents and educators ask pediatricians about the health effects of ELF-EMR on children. In particular, questions

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have been raised as to whether these and other ELF fields are carcinogenic. It is necessary to address these questions related to pediatric environmental health and advice on prevention.

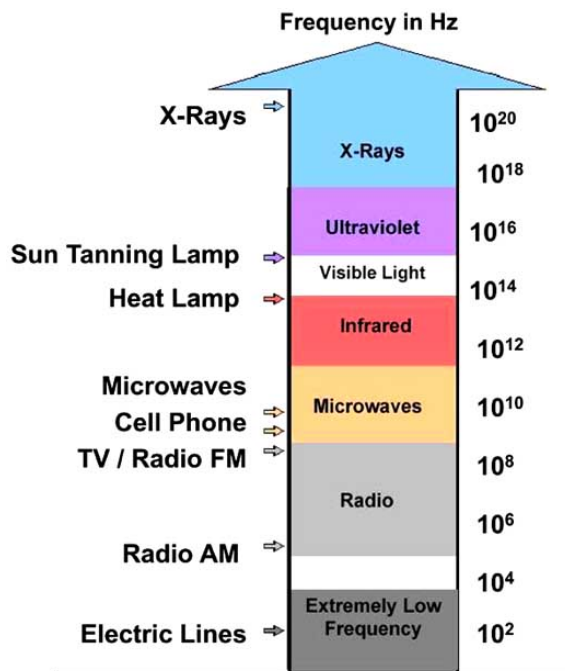


Fig. (1). EMR Diagram.

Classification of the electromagnetic spectrum is based on the frequency of oscillations (cycles per second or Hertz) and wavelength (meters).

ELF fields can interact with tissues by inducing electric fields and currents in them. This is the only established mechanism of action of these fields. ELF-EMR exposure can

cause adverse health effects, especially in the most vulnerable population-children [2].

Based on guidelines established by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the European Union recommendation of July 1999, chronic exposure levels of < 100 μT are considered safe for the general population. There are no specific indicated levels of exposure that are considered safe for children [3]. Yet, levels higher than 0.3-0.4 μT have been associated with a statistically significant increased risk of childhood acute leukaemia (AL) [4-6]. These disparities in the extent of exposure and safety criteria have generated uncertainty among various social sectors.

CONTACT WITH ELF-EMR

Electrical and magnetic fields of ELF-EMR are more intense near radiant bodies (Tables 1, 2 and 3) [7-9]. Various methods have been employed to insulate cables to prevent the harmful effects of electrical currents, which can have an impact if buried less than 200 m below ground [10].

In developed countries, every child is exposed to ELF-EMR in their home, school, during travel, and in social activities. Approximately 1% of children in western countries reside in close proximity to continuous ELHV's, which constitute the most powerful source of ELF-EMR emission [4, 11]. In the majority of cases, the average range of domestic exposure is between 0.05-0.1 μT. Table 4 shows sources of the magnetic fields from domestic appliances and illustrates two main points: First, that magnetic field strength around all appliances rapidly decreases the further you get away from them. Secondly, most household appliances are not operated very close to the body. At a distance of 1 m the magnetic fields surrounding most household appliances are lower than 0.2 μT.

Table 1. International Commission on Non-Ionizing Radiation Protection (ICNIRP)

Exposure Guidelines and Some Transmitting Sources [7, 9]		
Exposure	Guidelines of the ICNIRP for the General Population	Some Transmitting Sources
50 Hz	100 μT	50m lines of 400 K of power: 0.4-1.5 μT
60 Hz	83 μT	At home: usually < 0.1-0.4 μT
		0.5 m of TV: ≅ 0.2 μT
		0.03 m hair dryer:
		6-2.000 μT

Table 2. Electric Field (V/m) [8]

Voltage	Under the Line	at 30m from the Line	at 100m from the Line
400 KV	6.000	2.000	200
225 KV	4.000	400	40
90 KV	1.000	100	10
20 KV	250	10	-
220 V	1.2	-	-

Table 3. Magnetic Field (μT) [8]

Voltage	Under the Line	At 30m from the Line	At 100m from the Line
400 KV	30	12	1
225 KV	20	3	0.3
90 KV	10	1	0.1
20 KV	6	0.2	-
220 V	1.3	-	-

Table 4. Magnetic Field Values of Domestic Apparatuses Relative to Distance (μT) [8]

	3cm	30cm	1m
Electric Shaver	15-1500	0.08-9	0.01-0.03
Refrigerator	0.5-1.7	0.01-0.25	<0.01
Microwave oven	73-200	4-8	0.25-0.6
Slide projector	240	4.5	<0.15
Hair Dryer	6-2000	0.01-7	0.01-0.03
Vacuum cleaner	200-800	2-20	0.13-2
Portable radio	16-56	1	<0.01
Computer	0.5-30	<0.01	
Color TV	2.5-50	0.04-2	0.01-0.15
Refrigerator	0.5-1.7	0.01-0.25	<0.01
Dishwasher	3.5-20	0.6-3	0.07-0.3
Washing machine	0.8-50	0.15-3	0.01-0.04
Fluorescent Light	40-400	0.5-2	0.02-0.25

Average exposure at the residence: 0.005 – 0.1 μT .

MATERIAL AND METHODS

We reviewed the peer-reviewed literature published between 1979-2007 on adverse paediatric health effects of ELF-EMR in the following databases: Medline, Cancerlite, Science Citation Index, and Embase. The following key words were used for the search: children, health effects, reproductive outcomes, electromagnetic radiation of extremely low-frequency fields and residential electromagnetic radiation fields. Inclusion criteria for this review required that studies report the results of a meta-analysis, systematic review, or an original epidemiological study about childhood cancer and non-carcinogenic effects with measured or calculated magnetic fields of ELF-EMR. We compared these with the safety standards of international organizations.

ELF-EMR EFFECTS

Undoubtedly, electricity has numerous advantages and beneficial uses; however, it can also have deleterious effects not limited to acute electrical injury. ELF magnetic fields have been classified by the International Agency for Research on Cancer (IARC) as a “possible human carcinogen” and chronic effects of ELF-EMR occur in the setting of low, continuous doses over the course of months, years, and decades [1].

BRAIN TUMOURS

Children may be particularly sensitive to chronic exposure to ELF-EMR because of the greater susceptibility of their developing nervous system [4, 13]. First described in 1979 by Wertheimer and Leeper, children living in homes with high current-flow were believed to have had a 2.4-fold increase in the risk of dying from cancer of the central nervous system [14]. The study, however, was severely criticized for methodological issues. In recent years, several studies have been conducted in order to either refute or confirm the results of Wertheimer and Leeper [13-15, 21]. Yet these findings have not been conclusive and to date there are no better methods for the analysis of this association. Thus, in 2001 the National Radiological Protection Board of Great Britain concluded that there was no evidence of an association between tumors of the CNS and ELF-EMR [10].

ACUTE LEUKAEMIA

Since the studies conducted by Wertheimer and Leeper [21], numerous epidemiological studies have examined the association between ELF-EMR and childhood leukemia using different methods for measuring exposure [4, 6, 13, 16, 18, 19, 21, 22-26]. Many of the recent studies have documented effects on children that support the association between ELF-EMR and childhood ALL [6, 27].

In an attempt to combine the available studies in a systematic way, a pooled analysis was conducted by combining the primary data of all childhood leukemia studies with exposure assessments fulfilling certain quality criteria; Greenland *et al.* [28] analyzed the data of 15 epidemiological studies addressing ELF-EMR and ALL in children - 12 of which used direct measurements to quantify magnetic field exposure. The meta-analysis found no association between pediatric ALL and exposure to magnetic fields $< 0.3 \mu\text{T}$. However, when exposures of $< 0.1 \mu\text{T}$ were compared to those higher than $0.3 \mu\text{T}$, they found an OR of 1.7 (95% CI = 1.2-2.3). Moreover, Ahlbom *et al.* [29] analyzed nine epidemiological studies of ELF-EMR and ALL in children. In five of the studies, magnetic fields were measured for periods of 24 and 48-hours. In the remaining four studies, the magnetic fields were calculated, and not measured. No association was found between exposure to magnetic fields and childhood ALL when exposures were $< 0.4 \mu\text{T}$. However, at residential field exposures $> 0.4 \mu\text{T}$ (measured during the year prior to diagnosis), there was a statistically significant RR of 2.00 (95% CI 1.27-3.13). Furthermore, Angelillo *et al.* [30] evaluated 14 case-control studies and one cohort study. The meta-analysis based on wiring configuration codes yielded a pooled RR of 1.46 (95% CI of 1.05-2.04). Studies based on 24-hour measurements revealed a statistically significant RR of 1.59 (CI 95% 1.14-2.22). One must take into account the potential sources of error in epidemiological studies of EMR include errors in magnetic field measurement, disease classification, and field density.

Despite consistent associations between ELF-EMR and pediatric ALL, the greatest argument against the causal hypothesis is the absence of experimental evidence in animals or cell cultures. Nevertheless, confounding factors such as socioeconomic status, viral contacts, residence type, and traffic density have been examined exhaustively without finding or identifying another single factor or combination of factors that can refute the epidemiological association observed. In fact, the absence of an identified confounding factor can be used as an argument in favor of the causal association between ELF-EMR and childhood ALL [1, 8, 22, 23]. In addition, the possible effect of socioeconomic status, culture, and residential mobility on the outcome of these studies should be analyzed in future studies [5, 6].

In 2005, Draper *et al.* conducted a case-control study of the relationship between pediatric cancer and proximity of residency to ELHV [31]. The study included 29,081 children of 0-14 years born and diagnosed with cancer between 1962 and 1995, including 9,700 ALL cases. This is the largest epidemiological study to date, with approximately double the number of children living near ELHV than in previous studies. The 29,081 cases were compared to the same number of healthy controls, who were matched for sex, date of birth (± 6 months), and birth district. Cases were divided into three groups depending on the distances of their residences from the ELHV (> 600 m, 200-600 m, and < 200 m). A statistically significant association was found between childhood ALL and the proximity of the residence at birth to the ELHV source. A comparison of the subjects that live < 200 m with those that live > 600 m revealed a relative risk of developing ALL (RR = 1.23; 95% CI 1.02-1.49). There was no increased risk for developing other cancers.

In 2006, Foliart *et al.* examined the hypothesis that exposure to ELF-EMR influences the residual leukemia cells after ALL diagnosis [32]. This five year study included 482 children from the Pediatric Oncology Group diagnosed with ALL between 1996 and 2001. In spite of these study's limitations, results suggest that exposures to ELF-EMR fields $> 0.3 \mu\text{T}$ are associated with higher relapses and greater mortality in children diagnosed with ALL. In a different study conducted in Japan, magnetic fields were measured in the bedrooms of 312 children with ALL or acute myeloblastic leukemia (AML) and 603 controls [33]. It was concluded that children exposed to fields $\geq 0.4 \mu\text{T}$ had an increased risk (OR = 2.6; 95% CI 0.76-8.6) of developing AL compared to those exposed to fields $\leq 0.1 \mu\text{T}$. More significantly, for ALL cases alone the OR was 4.7 (95% CI, 1.15-19.0).

ELF-EMR AND PRENATAL EXPOSURE

There is limited scientific literature on the relationship between prenatal exposure to ELF-EMR and childhood ALL and studies have yielded contradictory results [1, 9, 27, 34]. Some studies found greater risk associated with the mother's occupation, but the maternal profession was not analyzed consistently. Infante-Rivard *et al.* conducted a study using an improved study design, and found a significant increase in the risk of developing childhood ALL with trans-placental exposures of $\geq 0.4 \mu\text{T}$ (OR = 2.5, 95% CI, 1.2-5.0) [35]. The occupations associated with relatively higher doses of exposure were electricians working in large plants ($0.7 \mu\text{T}$), operators of large electrical machines in textile factories ($0.68 \mu\text{T}$), and footwear manufacturers ($0.66 \mu\text{T}$). The plausibility of the described association is based on the proximity of the electrical apparatus to the pregnant women's abdomen, the special vulnerability of the fetus during gestation to polluting agents, and the average time of exposure from pre-conception to delivery.

ELF-EMR AND NON-CARCINOGENIC EFFECTS

The hypothesized non-carcinogenic effects of ELF-EMR include spontaneous abortion, congenital malformations, intrauterine growth retardation, low birth weight, and fetal death. Earlier studies have examined these effects in relation to EMR exposure from computer monitors. More recently, studies were conducted with electrical sources of residential exposure such as electric blankets and heated beds [36]. Some studies come to contradictory conclusions: while a study in the United States did not reveal a greater risk of spontaneous abortion in women exposed to video screens [37], a second study from Finland [38], found a significant increase in risk in women who used a video screen with high ELF-EMR ($> 0.9 \mu\text{T}$) (OR = 3.4, 95% CI, 1.4-8.6). The exposures to electrical blankets and water-bed heaters did not increase the risk of abortions or fetal abnormalities. Two studies that used body monitors to measure 24-hour ELF-EMR exposure found a two-fold increase in risk of spontaneous abortion when exposed to $2.3 \mu\text{T}$ compared to $1.6 \mu\text{T}$ [39, 40]. Given the conflicting data, it is difficult to conclude whether exposure to ELF-EMR produces any effect during pregnancy.

Other symptoms, such as electrical hypersensitivity and neurological effects, have been described in adults, but scientific studies have not confirmed their association with electromagnetic fields. In addition, studies on neurocognitive function yielded variable results. Similar symptoms and cognitive alterations have not been described in the pediatric population [37].

EXPERT COMMITTEES ACKNOWLEDGE RISK

In 1998, the Working Group of the U.S. National Institute of Environmental Health Sciences acknowledged evidence that residential exposure to ELF-EMR is potentially carcinogenic in children [9]. In 2001, both the U.K. National Radiological Protection Board and the ICNIRP Standing Committee on Epidemiology concluded that among all of the adverse effects evaluated in epidemiological studies concerning ELF-EMR, the strongest association was found between pediatric ALL and postnatal exposure to electromagnetic fields $\geq 0.4 \mu\text{T}$ [10, 41].

In June 2002, the IARC classified ELF-EMR as a "possible human carcinogen". Specifically, IARC classified the epidemiologic evidence on childhood leukemia as "limited" but the epidemiologic evidence on all other cancers and the animal evidence as "inadequate" [1]. "Possibly carcinogenic to humans" is a classification used to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals.

In January of 2005, the ELF Working Group-Federal-Provincial-Territorial Radiation Protection Committee of Canada concluded that exposure to very high levels of ELF-EMR resulted in a small, but significant risk increase for childhood ALL [34]. These statements reiterate a real association between the development of ALL in children and chronic exposure to high doses of ELF-EMR.

CAUSALITY HYPOTHESIS - ASSOCIATIONS OF EMR-ELF AND ALL

It is difficult to interpret epidemiological data in the absence of a clear, consistent, and reproducible biological mechanism that can explain the interaction of EMR-ELF in organic systems. Simple, linear biophysical models suggest that magnetic fields of 0.3-0.4 μT are weak and do not affect cells and tissues, and therefore most committees are reluctant to attribute risk at these low levels [3, 5, 9, 10].

A recent hypothesis suggested exposure to contact currents as a mechanism of biological plausibility [4, 6, 22, 42, 43]. When two parts of the body touch two points of different voltage potential, a small current is generated between the two points called "contact current". A difference of voltage potential exists between independent metallic structures in the same home. This difference in potential exists between faucets and other metallic water-drainage parts. When one hand turns the faucet while the other is submerged in water, the body receives a contact potential difference that generates a current between both hands. The voltage potential can be the result of different rates in loss of current, or due to induced currents in the circuits. The physical interaction between electrical current and the bone

marrow in extremities could be associated with childhood ALL. This hypothesis is based on the high correlation between residential magnetic fields and voltages, the fact that contact currents produce currents in children's bone marrow that are substantially higher than those produced by residential exposure to high magnetic fields, the anatomical and physiological characteristics of the bone marrow in children that render interactions strong enough to produce biological effects, and hygienic habits in the first few years of life, such as frequent baths [43].

Another hypothesis that suggests an association between EMR-ELF and childhood ALL is based on EMR-ELF exposure results in the deregulation of melatonin [8, 22, 42, 44]. Melatonin, a hormone secreted by the pituitary gland, helps regulate sleep-wake cycles, and acts as an eliminator of free radicals and oxidants. Theoretically, these effects help protect the human haematopoietic system from oxidative damage. Therefore, aberrations of the haematopoietic system may lead to transformations resulting in leukemia. Most of the studies overlook mutagenic effects associated with EMR-ELF [1, 23, 34, 45]. EMR-ELF may have a tumor promoting effect given that in some types of childhood ALL are associated with chromosomal aberrations during the first trimester. To achieve neoplastic transformations later in life, there would need to be an initiator, such as EMR-ELF. In most instances, this would occur during the early infant period [2, 46-48].

ENVIRONMENTAL LEGISLATION AND PEDIATRIC HEALTH

Three studies have estimated the potential number of childhood leukemia cases attributable to EMF exposure [28, 49, 50]. These suggest that as many as 120-175 additional cases per year in the US/North America may result from residential exposure alone. The current recommendation for occupational CNS exposures to induced currents is $< 10 \text{ mA/m}^2$ (equivalent to electric fields of approximately 100 mV/m). The permissible levels of public exposure to electric and magnetic fields are 5KV/m and 100 μT , respectively [1, 3, 8]. These numbers were based on studies using adult populations, not including pregnant women or children. The differences in the bioelectric properties of vulnerability (both functional and anatomical) in fetal and infant periods must be addressed in order to provide norms that are effective, convincing, and comprehensive [1, 3, 30, 43]. The adoption of political and legal decisions that take into account the effect of EMR-ELF on the pediatric population is a complex process. Nevertheless, it is necessary to apply scientific knowledge to protect the most vulnerable populations, and to apply measures of precaution. It is imperative to make the public aware of the scientific evidence available. In our experience, some neighborhoods and educational communities have required the application of the principle of precaution and an ample information process for all stakeholders involved. The key in making public health decisions is having a well-informed society. When a society can interpret the cost-benefit analysis, it is better able to decide its future without lengthy, costly, and often incomplete risk assessments, especially in regards to complex diseases characterized by long latent periods. On the other hand, at the Pehsu, we have developed a "pediatric environmental

history”, an individual risk assessment tool, which has allowed us to recognize that in the vast majority of childhood cancer cases others risk factors are associated with cancer with more conclusive evidence than ELMF.

At the June 2004 “The Future of Our Children” conference in Budapest, the “Children Environment and Health Action Plan for Europe”, which promotes the reduction of the exposure to electromagnetic fields, was adopted. The Final Ministerial Declaration recognized prudent avoidance to be a worthy goal in areas where it is necessary to combine preventive actions with precautionary measures, such as where there is little current evidence and insecurities are high, and where exposures can result in serious and irreversible consequences [51-55]. The World Health Organization, the European Commission and the National Institute of Environmental Health Science are developing and implementing protective measures for ELF EMF, and also the Guidelines for Application of the Precautionary Principle.

In conclusion, the recommendations provided by EMF applications are evaluated and classified into those based on scientific grounds (SG), into those based on the precautionary principle (PP) and those based on a more or less emotional base (“gut feeling”, GF). Pediatricians promoting a healthy environment for children should recommend that [56]: 1) New homes, kindergartens and schools should preferably be built at a distance of more than 100m from high voltage power lines and transformers (SG, epidemiological data). 2) The electrical wiring in a residential house should be designed in a way as to minimize exposure to magnetic fields (SG, epidemiological data). 3) In the bedroom a switch should be installed “to switch off electricity” during night time (PP). 4) Clock radios should be placed at a distance of at least 1 m from the bed or be replaced by battery-operated alarm clocks (GF).

CONCLUDING REMARKS

ELF-EMR is present in the industrialized world and generated by facilities that produce, transport, transform, and deposit or apply electrical energy. In industrialized countries, most homes are exposed to average magnetic densities produced by electrical energy of $< 0.1 \mu\text{T}$. The average residential exposure to magnetic field densities is $\geq 0.3\text{-}0.4 \mu\text{T}$ and is associated with an increased risk for developing childhood ALL. It is difficult to demonstrate an association between chronic exposures to densities $\geq 0.3\text{-}0.4 \mu\text{T}$ and increased risk of developing childhood ALL due to the lack of evidence of the biological mechanisms and its irreproducibility in animal studies. More importantly, while ELF magnetic fields have been classified by the IARC as a “possible human carcinogen”, the United Nations, World Health Organization, and the European Union recommend the use of the Precautionary Principle in incorporating all technological and industrial processes.

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