Childhood Leukemia and Residential Exposure to Weak Extremely Low Frequency Magnetic Fields

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There is no known mechanism by which magnetic fields of the type generated by high voltage power lines can play a role in cancer development. Nevertheless, epidemiologic research has rather consistently found associations between residential magnetic field exposure and cancer. This is most evident for leukemia in children. — Environ Health Perspect (Suppl 2):59–62 (1995)

Key words: childhood leukemia, electromagnetic fields, epidemiology, neoplasms, review

Introduction

Magnetic fields are generated by electric currents flowing through conductors. Thus, magnetic fields exist wherever there are electric currents and are thus ubiquitous in modern society. The characteristic of a magnetic field is determined by the strength of the electric current and by its frequency. The frequency in power lines, appliances, and other common sources is 50 Hz in Europe and 60 Hz in North America. Fields from power lines and other sources in the environment are so weak that the induced currents in human bodies are several orders of magnitude weaker than those induced by electric activity in nerve and muscle cells and the energy is too weak to break chemical bonds. Despite extensive experimental research, there is to date no known mechanism by which such fields can play a role in cancer development.

The epidemiologic literature on potential health effects of electric and magnetic fields has been reviewed several times by task groups such as the Oak Ridge Associated Universities panel in the U.S., the British Radiological Protection Board, and by independent scientists (1–4). The conclusion has invariably been that there is not sufficient evidence for a firm conclusion in either direction. However, the credibility given to the hypothesis of a link between magnetic fields and health effects varies among reviewers. The basis for the different conclusions is mainly varying weight put to the lack of a known possible mechanism and different weights given to the likelihood of systematic errors in some of the studies.

It is clear that there are inconsistencies within the epidemiologic literature. Some childhood cancer studies have found associations between magnetic fields and central nervous system cancers while others have not. Also in the occupational literature the studies vary with regard to type of cancer for which effects are seen. There is also inconsistency between occupational studies and residential adult cancer studies in that most residential studies on adults have not found effects while most occupational studies have. Furthermore, several of the studies use different methods to estimate magnetic field exposure and the results depend on the method of choice in a manner that is not self-explanatory (below). The reasons for these inconsistencies are not known, although in some instances there are good hypotheses that may provide at least partial explanations. One example is the lack of association in most adult residential studies. A closer look reveals that several of those studies simply have too small a number of exposed subjects to provide any meaningful information for specific cancer sites (5,6). Thus, for adults and residential exposure there are actually very few data at hand. Despite these inconsistencies, there is actually a rather good consistency across subgroups. One such area is the studies on childhood leukemia and residential magnetic field exposure.

Childhood Leukemia Studies

The childhood leukemia studies are given special attention here because this is the group with a reasonable number of reports that display the highest consistency across studies.

We are currently aware of ten studies with information on leukemia in children and residential exposure to magnetic fields, including three recent Nordic investigations. The original Wertheimer and Leeper study from 1979 has been discussed extensively and also criticized (7). Although it is true that the study has some unorthodox features, no one has been able to point to a systematic error that might explain the findings. One area of criticism was the use of wire codes to assess magnetic field exposure. Wire codes are a way of classifying homes according to type and distance to nearby lines. However, it has been shown that wire codes indeed provide a reasonable classification by magnetic field. The size of the study and the strength and consistency of the findings rule out chance as an explanation. This study was followed by an investigation that showed no association between wire codes and childhood leukemia, but the control selection in the latter work has been justifiably criticized as having the potential of leading to underestimation of the relative risk (8,9).

One study by Tomenius was not published until 1986, although it actually was conducted shortly after the Wertheimer and Leeper report. It shares some problems with other studies, which were designed at a time when less was known about magnetic field exposure distribution and measurements (10). To measure exposure, Tomenius used the presence of a visible 220 kV line within 150 m (paved by foot) and alternatively a short-term magnetic field reading outside the front door of the building, often an apartment building. For leukemia, Tomenius (10) found a relative risk close to unity when distance to lines was used and a considerable under-risk when front door readings were used. We now have clear indications that neither of those approaches provides a valid magnetic field assessment in the home. The 150-m range is much too wide to be meaningful.
A short-term reading outside the front door is only a reasonable predictor of indoor magnetic fields if there is a dominant external magnetic field source, such as a high voltage line, near the home. There are also other difficulties with the study, such as the use of dwellings rather than individuals as the observational entity.

There are two British studies to consider. One was originally an adult leukemia study but has been extended to include those below 18 years of age (11). It uses a crude approach to exposure assessment that classifies as exposed everyone who has a substation within 50 m of their homes. They find a slightly elevated relative risk. The other study is not properly a leukemia study but combines all nonsolid tumors into one disease entity (12). It uses a sophisticated procedure for exposure assessment whereby magnetic fields in the homes are calculated from information about nearby lines. However, only 1 case out of a total of 374 and 4 controls out of a total of 588 have calculated fields exceeding 0.1 μT; most studies are based on cut-off points of at least 0.2 μT. The reason for this low proportion of exposed subjects is not known but it renders the study virtually void of information.

Perhaps the most frequently cited studies on childhood cancer and magnetic fields are one by Savitz et al. (13) and one by London et al. (14). Both find clear associations with childhood leukemia when magnetic field exposure is assessed through wire codes but much weaker associations when actual magnetic field readings are used. This seemingly contradicting result might, however, be explained by the findings in the Swedish study that there was a poor correlation between calculated historic fields and contemporary short-term readings; one explanation may be that wire codes are better predictors of long-term exposure. Both studies have also been discussed with respect to control selection bias, but for different reasons. In the Denver study, the controls may have been less mobile than the cases and in Los Angeles the random digit dialing procedure may have resulted in some bias. However, these methods are commonly used in the United States and it is difficult to assess the importance of these potential systematic errors, if any.

A Swedish study was performed on the population living within a corridor around the country’s 220 and 400 kV lines during a 26-year period; the corridor was defined wide enough so that the outer part was unaffected by magnetic fields generated from the line (15). The study took advantage of the Swedish population registry system including the cancer and mortality registries. This made it possible to identify the study population carefully, to identify cases of cancer, and to select controls. Thus, this design should minimize the risk of selection bias.

The approach to exposure assessment was based on the assumption that for those living close to high voltage lines, the dominant source of electromagnetic field exposure would be the nearby line. Provided that one has access to information about configuration, load, and relevant geographic parameters, the magnetic field generated from the line can be calculated. Short-term measurements and calculations were performed based on conditions at the time of the measurements and it was found that calculations did indeed predict the measured fields with reasonable accuracy. However, this accuracy was considerably higher in single-family homes than in apartments. Historic load information for the involved transmission lines was also available. This made it possible to calculate annual averages of the fields for the year of diagnosis for each case and corresponding controls. These calculated fields did not show a reasonable correlation with the measured fields, indicating that contemporary short-term readings are poor predictors of annual averages of historic fields. This suggests an explanation for the apparent inconsistency in some previous studies that have found associations with cancer risk when wire codes were used but not when actual measurements were used. However, more research is needed about the interrelationship between spot measurements at one time and various power-line based magnetic field estimates at another time or period. Such research is going on, e.g., based on the data collected in the Swedish study.

When historic calculations were used as exposure assessment for childhood leukemia and with cut-off points at 0.1 and 0.2 μT, the relative risk (RR) increased over the two exposure levels and was estimated at 2.7 (95% CI: 1.0–6.3) for 0.2 μT and over. These results persisted when adjustments were made for potential confounding factors. For central nervous system tumor, lymphoma, or for all childhood cancers together there was no support for an association. There were no associations with measured fields. Thus, in short, the study showed an association between calculated historic magnetic fields and childhood leukemia, but not with other childhood tumors and not when measured fields were used. The weakest point of this study seems to be the small numbers. Despite the fact that the entire country was included as well as the entire period for which the cancer registry has been in operation, the critical numbers, i.e., the numbers of exposed cases, are low. However, the magnitude of the relative risk estimates and the accompanying confidence intervals, together with the internal consistency of the results, speak against chance as the explanation for the observed association. It was concluded that overall, the study gives more support for an association between magnetic field exposure and cancer incidence than against.

A similar study was conducted by the Danish Cancer Institute. The institute was commissioned to include a magnetic field component in an ongoing childhood cancer study with different objectives (16). The study was a population-based case–control study including all cases of leukemia, lymphoma, and brain cancer in children in Denmark. Denmark has a well-functioning cancer registry which was used as the source for the cases. Controls were selected randomly, matched for basic demographic characteristics. The main difference is that in the Swedish study the population was restricted to those living in the power line corridor, while in the Danish study the population in the entire country was included. The approach to assessing magnetic field exposure was similar, but the Danish study did not include any spot measurement component. One other difference was that the Danish study did not include all childhood cancers, but only the selected types mentioned.

In many respects, the Danish study has similar strengths as the Swedish work; again, the major weakness appears to be the limited size. This weakness is more marked in the Danish study since Denmark is smaller and hence the numbers are smaller. The fact that the Danish study includes all Denmark while the Swedish study only includes the power line corridor does not change this since the limiting number eventually is the number of exposed cases not the total number of cases or subjects in the study.

The results have been discussed mainly with respect to a high estimated relative risk of lymphoma. In our view, however, the most important aspect of the results might be the leukemia relative risk that was estimated at 1.5 for a magnetic field of 0.25 μT or more. Even though it is a modest elevation, this result is compatible with the leukemia results in the Swedish study (below).
A study on childhood cancer similar to those of the other Nordic countries has also been conducted in Finland (17). However, the conditions with regard to available information were different and the Finnish study has some diverging features. More information about the population was computerized in Finland than in the other countries. This made it possible to base the research entirely on digitized information, which in turn made a cohort study possible. The advantage of the cohort approach is that there is no random variation and no risk of selection bias from the control selection. The disadvantage is that exposure assessment may be less detailed. In Finland, distance between line and building and all other information on which exposure assessment was based was obtained from computerized registries. For a magnetic field of 0.2 \( \mu \text{T} \) or more the main results of the study were a relative risk estimate of 1.6, and 2.3 for leukemia and nervous system tumors respectively. For all cancers together, the relative risk was estimated at 1.5.

The three Nordic studies have also been pooled in a joint analysis (18). The justification was that despite certain differences, the three studies were considered similar enough in design to conclude that chance would be the major source of differences in results. This would also partly make up for the small numbers in the individual studies. The joint analysis resulted in a relative risk of 2.1 (95% CI: 1.1–4.1) for leukemia.

Thus, the ten available studies provide information of varying quality and a few should be given less weight when combining findings across studies. The results of these studies are summarized in Table 1. Results referring to wire codes or line based estimates of the fields have been used rather than measured fields. With three exceptions (8,10,12), all studies have relative risk estimates in the range of 1.5 to 3.0. Thus, the evidence on leukemia in children appears rather consistent.

### Discussion

There is evidence supporting the theory that exposure to magnetic fields of the type generated by power lines is of importance for the development of cancer, but experimental research has been unable to disclose a mechanism. Few reviewers would be willing to conclude that the epidemiologic data are so strong that the hypothesis can be considered proven. Therefore, unless the theory is rejected on theoretical grounds we have to accept the uncertainty, which indeed may last for some time. From the scientific point of view there is no problem with that and scientists are used to the limitations of current knowledge.

From the public health point of view the situation is more complicated, since this research has received extensive media attention, which in turn has created great concern among the public and politicians. However, even on the assumption that a causal association between magnetic fields and cancer were proven beyond reasonable doubt, there would still remain difficulties from the public health perspective. There are several reasons for this. First, the affected cancer diagnoses would not be known. The most compelling evidence seems to exist for leukemia in children but there are also other cancers for which there is some evidence. Second, since the relevant dosimetry is not known, it is not possible to estimate the number of exposed persons or the relative importance of various magnetic field sources such as power lines and appliances of different sorts. There is, for example, no information on whether short-term exposure to strong fields is equivalent to long-term exposure to weak fields. We do not know if exposure at night would be of more relevance than daytime exposure. On the very simplistic assumption that residency close to high-voltage power lines (in Sweden 220 and 400 kV) would double the childhood leukemia incidence, it may be estimated that less than one case per year out of a total of 70 would be prevented were all power lines deenergized.

The reason for the low number is the combination of an uncommon exposure and a rare disease. It is the responsibility of politicians, power line owners, and individuals to decide what action is warranted in a situation like this. One should remember, however, that we all have difficulties dealing with risks. This is particularly true in a situation in which there remains uncertainty about basic facts and in which the risk is low but the putative consequence severe.

### Table 1. Summary of results from ten childhood leukemia studies on residential magnetic field and leukemia (power line-based exposure assessment).

| Author | Relative risk (95% CI) |
|--------|------------------------|
| Wertheimer and Leeper (9) | 3.0 (1.8–4.8) |
| Fulton et al. (8) | 1.0 (0.6–1.8) |
| Tomenius (10) | 1.1 (0.3–4.1) |
| Savitz et al. (13) | 2.9 (0.9–8.0) |
| Coleman et al. (11) | 1.5 (0.7–3.4) |
| Myers et al. (12) | 0.8 (0.07–9.6) |
| London et al. (14) | 2.2 (1.1–4.3) |
| Feyching and Ahlbom, (15) | 2.7 (1.10–6.3) |
| Olsen et al. (16) | 1.5 (0.3–6.7) |
| Verkasalo et al. (17) | 1.6 (0.3–4.5) |
| Total Scandinavian studies (18) | 2.1 (1.1–4.1) |

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