

Magnetic Fields and Breast Cancer in Swedish Adults Residing near High-Voltage Power Lines

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We conducted a case-control study to test the hypothesis that residential magnetic field exposures increase the incidence of breast cancer. The study was based on people who had lived within 300 m of 220- or 400-kV power lines in Sweden at any time between 1960 and 1985. We identified 699 cases of breast cancer in women and 9 cases in men. One matched control per female case and eight per male case were selected at random. Estrogen receptor information was available for a subset of female cases. We assessed magnetic field exposure through calculations of the magnetic fields generated by the power lines before diagnosis. For calculated magnetic field levels ≥ 0.2

microtesla (μT) closest in time before diagnosis, we estimated the relative risk to be 1.0 [95% confidence interval (CI) = 0.7–1.5] for women and 2.1 (95% CI = 0.3–14.1) for men. Women younger than 50 years of age at diagnosis had a relative risk of 1.8 (95% CI = 0.7–4.3). For women with estrogen receptor-positive breast cancer, the relative risk was estimated at 1.6 (95% CI = 0.6–4.1), using the exposure cutoff point $\geq 0.1 \mu\text{T}$. Among estrogen receptor-positive women younger than 50 years at diagnosis, the relative risk increased to 7.4 (95% CI = 1.0–178.1). (Epidemiology 1998; 9:392–397)

Keywords: breast neoplasms, electromagnetic fields, case-control study, gender.

Recently, a National Academy of Sciences committee¹ concluded in a review that there is no conclusive and consistent evidence that exposure to residential electric and magnetic fields produces cancer. This conclusion seems to be based largely on the lack of experimental data that can explain the mechanism by which electric and/or magnetic fields could interact with biological systems to produce cancer.

In 1987, Stevens^{2,3} presented the hypothesis that use of electric power may increase the risk of breast cancer. The proposed mechanism is an effect of electromagnetic field exposure on the pineal nighttime melatonin production and a relation between melatonin and breast cancer. It has been suggested that electromagnetic field exposure has the same suppressive effect on melatonin production as light at night. In animal studies, change in melatonin levels has been the most consistently reported effect of such exposures.⁴ Few studies have been performed with human subjects, and the results have been contradictory.^{5–9} It has also been suggested that lower levels of melatonin lead to an increase in circulating estrogen levels, which would increase susceptibility to

sex hormone-related cancers. Other mechanisms have also been proposed; Hill and Blask¹⁰ demonstrated an oncostatic effect of melatonin on estrogen receptor (ER)-positive breast cancer cells, and some studies have indicated an effect of melatonin on the immune system.¹¹ It has also been suggested that melatonin acts as a potent antioxidant.¹²

Most epidemiologic studies of the association between electromagnetic field exposure and breast cancer have focused on occupational exposure,^{13–25} but there are some studies of residential exposure from power lines^{26–30} and other domestic sources.^{31,32} The majority of the occupational studies have focused on male breast cancer,^{13–21} and several of the studies have indicated an association.^{13–18} Studies of electromagnetic field exposure in relation to female breast cancer have yielded mixed results.^{22–34}

The purpose of the present work was to test the hypothesis that residential magnetic field exposure of the type generated by high-voltage power lines increases the incidence of breast cancer in women and men.

Subjects and Methods

STUDY BASE

This study is based on the same population as the previously reported studies of childhood cancer³⁵ and of leukemia and central nervous system tumors in adults.³⁶ The identification of the study population has already been described in detail elsewhere³⁵ and will only briefly be related here. The study base comprised the person-years of everyone age 16 years or more who had lived for at least 1 year on a property located within 300 m of any

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of the 220- and 400-kV power lines in Sweden during the period 1960–1985. The corridor around the power lines is wide enough to include both exposed and unexposed subjects. All properties at least partly located within the power line corridor were identified, and the population registry was used to identify the individuals who had lived on the listed properties. About 400,000 people were identified within the power line corridors. On the basis of a validation of the exposure assessment method reported in a previous study,³⁵ we decided that among women, only subjects living in single-family homes would be included. All male breast cancer cases were included.

The subjects were followed from either 1960, the day they turned 16 years of age, or the time when they moved onto a property located within the power line corridor, whichever came last. Follow-up continued through 1985 or to the time of cancer diagnosis or death, whichever came first, regardless of whether the subjects were still living within the power line corridor.

CASES AND CONTROLS

The study was designed as a case-control study nested within the cohort. We identified cases of malignant breast cancer (*International Classification of Diseases*, 7th revision, code 170) through record linkage to the Swedish Cancer Registry, which is operated by the National Board of Health and Welfare. For all cases, we ascertained that the individuals had lived within the power line corridor for at least 1 year before diagnosis. We obtained information about ER status for a subset of cases. Tests for ER status have not been performed routinely in Sweden until the last few years, and therefore information about ER status was sought in medical records for cases having occurred during 1980–1985.

We selected one control per female case randomly among those who were included in the study base during the year of diagnosis of the matched case and who were of the same 5-year age group, lived in the same parish during the year of diagnosis (or, if the case had moved out before diagnosis, during the last year before moving out, had lived within the corridor for at least 1 year before the reference date), and lived near the same power line as the case. We selected eight controls per male case using the same matching criteria. In some parishes, there was an insufficient number of individuals fulfilling all of the matching criteria. In those instances, an eligible control was sought among subjects living near other power lines within the same parish, or in an adjacent age group. If a control still could not be found, the area was increased to include other parishes within the same town. Despite these adjustments in the matching criteria, a control could not be found for four cases of female breast cancer.

MAGNETIC FIELD ASSESSMENT

We defined residential magnetic field exposure as the magnetic fields generated by power lines close to the house. No attempt was made to estimate exposure from

internal sources in the house. We assessed the magnetic field exposure through theoretical calculations of the magnetic fields in the home generated by the power lines using a computer program developed by the State Power Board (available through Vattenfall Utveckling AB, Vällingby, Sweden). The calculations took account of the height of towers, distance between towers, distance between phases, ordering of phases, distance between the power line and the house, and average load on the power line during the year most closely preceding diagnosis. Calculations were also made based on the load of the power line in each of the 6 years preceding diagnosis. All types of power lines (transmission lines and distribution lines) within 300 m of the house were included in the calculations, except for buried cables. Information about the historical load on the 220- and 400-kV power lines was available from detailed records of the operation of the different lines.

A validation of the calculated magnetic fields³⁵ indicated that they are a valid predictor of measured magnetic fields in single-family homes but are less valid in apartment houses. In apartment houses, the discrepancy between magnetic field measurements and calculated fields was mostly confined to houses with low calculated fields but high measured fields. It is likely that other sources of magnetic field exposure are more common in apartment houses than in single-family homes.

EXPOSURE DEFINITION

We defined exposure as the average magnetic field exposure during the year most closely preceding diagnosis in which the case or corresponding control had lived within the power line corridor. To ensure that the results were not sensitive to the choice of cutoff points, we used several different cutpoints [0.1, 0.2, and 0.5 microtesla (μT)], comparable with those used in previous studies of residential magnetic field exposure.^{35,37,38} We also examined the effect of exposure 1 and 5 years before diagnosis and of cumulative exposure during the 6 years immediately preceding diagnosis. For cumulative exposure, we used the cutpoints <0.5 , 0.5 – 2.9 , and ≥ 3.0 μT -years. The upper cutpoint corresponds to an annual average exposure of 0.5 μT . We also present results based on distance to the power line, using the cutoff points 0–50, 51–100, and ≥ 101 m.

CONFOUNDERS AND EFFECT MODIFIERS

We stratified the data according to age (<50 or ≥ 50 years), sex, and ER status. ER status was considered positive when a value greater or equal to 10 fmol per mg protein or 0.10 fmol per μg DNA was found.

We obtained information about socioeconomic status from the censuses performed by Statistics, Sweden, every 5th year. The censuses from 1960 on are available on computer, and they include information about socioeconomic status for all census years except 1965. The information was taken from the last census before diagnosis. If information about socioeconomic status was missing in that census, we sought earlier censuses. The socioeconomic in-

TABLE 1. Number of Breast Cancer Cases and Controls According to Demographic Characteristics

	Women		Men	
	Cases	Controls	Cases	Controls
Total	727	729	9	72
Missing exposure information	16	20		
Number available for analyses	711	709	9	72
Number of complete pairs	699	699	9	72
Age at diagnosis (years)				
<50	190	194		
≥50	509	505	9	72
Area				
Stockholm	173	159	3	24
Rest of Sweden	526	540	6	48
Time period				
1960–1974	244	244	4	32
1975–1985	544	544	5	40

dex in the censuses is based on occupation. Each housewife is categorized according to her husband's occupation. For about 1.5% of the subjects, a socioeconomic index still could not be found; we excluded these subjects from all analyses that required this information.

STATISTICAL METHODS

We used conditional logistic regression for matched analyses.³⁹ The random variability was assessed by 95% confidence intervals (CI).

Results

Table 1 shows descriptive information about cases and controls. The total number of female controls exceeds

the number of cases, because whenever the exact location of the residence for a control was unobtainable, another control was selected. We identified a total of 727 female breast cancer cases, and the corresponding number of controls was 729. We found a matched control for all but 4 cases. For some pairs, exposure information was missing for either the case (N = 16) or the control (N = 20). Thus, 699 complete female pairs were available for analysis. The number of male cases was 9, and the corresponding number of controls was 72.

Table 2 shows the results obtained when we defined the exposure as the average exposure during the year most closely preceding diagnosis, with the exposure categories 0.1–0.19 μT and

≥0.2 μT . The relative risk estimates for the whole group of women were close to unity. Age-specific analyses revealed an elevated relative risk among younger women, estimated to be 1.8 (95% CI = 0.7–4.3) among women exposed to ≥0.2 μT . The relative risk for older women was close to unity. For men, the relative risk in the highest exposure category was 2.1 (95% CI = 0.3–14.1) and was based on only two exposed cases. There was no case in the intermediate exposure category. Among men we conducted no further analysis that used calculated fields to estimate magnetic field exposure.

For the exposure categories 0.1–0.49 μT and ≥0.5 μT , we estimated the relative risk for younger women to be 1.3 (95% CI = 0.7–2.6) and 2.6 (95% CI = 0.5–

TABLE 2. Breast Cancer Relative Risk Estimates (RR) and 95% Confidence Intervals (CI) According to Calculated Magnetic Fields Closest in Time before Diagnosis, Using Cutoff Points at 0.1 and 0.2 μT

Gender and Age (Years) at Diagnosis	<0.1 μT *		0.1–0.19 μT				≥0.2 μT			
	Cases	Controls	Cases	Controls	RR	95% CI	Cases	Controls	RR	95% CI
Women										
All ages	588	596	57	49	1.2	0.8–1.8	54	54	1.0	0.7–1.5
<50	161	169	14	12	1.2	0.6–2.8	15	9	1.8	0.7–4.3
≥50	423	424	43	36	1.2	0.7–1.9	39	45	0.9	0.5–1.4
Men										
All ages	7	60	0	3			2	9	2.1	0.3–14.1

* Reference category.

TABLE 3. Breast Cancer Relative Risk Estimates (RR) and 95% Confidence Intervals (CI) in Women According to Cumulative Magnetic Field Exposure during the 6 Years Immediately Preceding Diagnosis, Using Cutoff Points at 0.5 and 3.0 μT -Years

Age (Years) at Diagnosis	0.5 μT -Years*		0.5–2.9 μT -Years				≥3.0 μT -Years			
	Cases	Controls	Cases	Controls	RR	95% CI	Cases	Controls	RR	95% CI
All ages	543	556	101	96	1.1	0.8–1.5	25	17	1.6	0.8–3.2
<50	152	158	28	26	1.2	0.6–2.2	6	2	3.1	0.6–15.6
≥50	388	395	72	69	1.1	0.7–1.6	19	15	1.4	0.6–2.9

* Reference category.

TABLE 4. Breast Cancer Relative Risk Estimates (RR) and 95% Confidence Intervals (CI) in Women in Relation to Calculated Magnetic Fields Closest in Time before Diagnosis Using 0.1 μ T as the Cutoff Point, According to Estrogen Receptor (ER) Status

	<0.1 μ T*		$\geq$ 0.1 μ T		RR	95% CI
	Cases	Controls	Cases	Controls		
All cases with ER information	82	82	20	20	1.0	0.5-2.2
ER ⁺	55	59	17	13	1.6	0.6-4.1
ER ⁻	27	23	3	7	0.2	0.0-1.7
Age (years) at diagnosis						
<50, ER ⁺	21	26	6	1	7.4	1.0-178.1†
$\geq$ 50, ER ⁺	34	33	11	12	0.9	0.3-2.6

* Reference category.

† Unmatched analysis.

13.5), respectively (five cases and two controls in the highest exposure category). Results for women $\geq$ 50 years were close to unity.

Table 3 displays the results for cumulative exposure. We estimated the overall relative risk to be 1.6 (95% CI = 0.8-3.2) for exposures $\geq$ 3.0 μ T-years. Again, we found a higher risk estimate for younger women.

Control of confounding from socioeconomic status did not alter the results materially (not shown). When we defined the exposure as the average exposure 1 and 5 years before diagnosis, the results were virtually unchanged (not shown).

Table 4 shows the results stratified on ER status. These analyses were based on the subgroup of cases and controls for whom ER information was available. Accordingly, a smaller number of cases was available, and therefore, we conducted the analyses using a dichotomous exposure estimate, with a cutoff point of 0.1 μ T. For the total group with information about ER status, we estimated that the relative risk was 1.0 (95% CI = 0.4-2.2). The corresponding estimate for ER-positive subjects was 1.6 (95% CI = 0.6-4.1) and for ER-negative subjects 0.2 (95% CI = 0.0-1.7). Age-specific matched analyses were not feasible because of small numbers, but an unmatched analysis of ER-positive subjects younger than 50 years at diagnosis yielded a relative risk of 7.4 (95% CI = 1.0-178.1), based on six exposed cases and one exposed control.

Table 5 displays the results using distance alone as exposure estimate. The overall risk estimates for women were close to unity. Results for women below 50 years of

age were 1.5 (95% CI = 0.9-2.7) in the intermediate exposure category and 1.6 (95% CI = 0.7-3.8) in the highest category. The results for men were based on only three cases living within 100 m of a power line.

Discussion

Women living in homes with elevated magnetic field exposure originating from high-voltage power lines close to the house had no overall increase in breast cancer risk. The results, however, indicated an increased risk for exposed women under age 50 years, but these results were based on a small number of subjects. The number of male breast cancer cases was even smaller, and the risk was slightly increased.

The study was designed to avoid selection bias. Exposure was defined as magnetic fields generated by power lines close to the house, and the access to records of historical loadings on the power lines made it possible to estimate the magnetic field exposure before diagnosis. We made no attempt to measure exposure from internal sources in the house, which may have introduced some misclassification of the exposure. Close to the power line, the magnetic field exposure from internal sources is unlikely to exceed that from the power line, but some of the subjects classified as unexposed may be exposed from such sources. There is no reason to suspect that this exposure would affect cases and controls differently, and the effect of such misclassification would be a dilution of the effect estimate. A more severe source of exposure misclassification is occupational magnetic field expo-

TABLE 5. Breast Cancer Relative Risk Estimates (RR) and 95% Confidence Intervals (CI) in Relation to Distance to Power Line

Age (Years)	$\geq$ 101 m*		51-100 m				$\leq$ 50 m			
	Cases	Controls	Cases	Controls	RR	95% CI	Cases	Controls	RR	95% CI
Women										
All ages	553	547	115	114	1.0	0.7-1.3	44	51	0.8	0.5-1.3
<50	142	155	38	29	1.5	0.9-2.7	15	11	1.6	0.7-3.8
$\geq$ 50	408	390	76	83	0.9	0.6-1.2	29	40	0.7	0.4-1.1
Men										
All ages	6	56	2	9	2.1	0.4-11.6	1	7	1.4	0.1-15.0

* Reference category.

sure. Individuals in the working population spend a large proportion of their time outside of the home, and a Swedish study has indicated that the magnetic field exposure may be substantial for many occupations.⁴⁰ Again, there is no reason to suspect differential exposure misclassification, but the effect of this misclassification might be a bias toward the null. If occupational magnetic field exposure is positively correlated with residential exposure, failure to account for occupational exposures may lead to positively biased effect estimates.^{41,42} There is no reason to suspect such a correlation, however.

The study was designed to measure magnetic field exposure close in time before diagnosis, consistent with the hypothesis of a promoting effect of magnetic field exposure. Therefore, it is less well suited to study the effect of exposure early in reproductive life, one of the mechanisms proposed by Stevens,³ especially in postmenopausal cases.

We had only limited control of potential confounding. Nevertheless, it seems unlikely that reproductive characteristics, for example, would differ for subjects living close to and farther from a power line. The study covers a period before discussions about possible health effects from magnetic field exposure. Furthermore, the control of confounding from socioeconomic status may to a certain degree have controlled these factors.

Female breast cancer is a common disease, and consequently the study is based on a large number of cases. Nevertheless, in the age category in which we found an association, the disease is uncommon. Thus, chance may be an explanation for the observed association. Another possibility is that with a low background rate of disease, stronger associations can be found, whereas the risk may be attenuated in a population with a high background incidence.⁴³ In the analyses of male breast cancer, the cases were few, and the results do not allow any clear conclusion.

The finding of an elevated risk among exposed women in the youngest age category is consistent with the results from several of the previous studies. In a study of residential electromagnetic field exposure and cancer, an association was found between wire codes and premenopausal, but not postmenopausal, breast cancer.²⁶ This finding was not confirmed in two studies of residential magnetic field exposure, one in Finland and one in Taiwan,^{29,30} in which no association was found. The Finnish study did not examine age-specific effects.²⁹ Other studies of residential magnetic field exposure and breast cancer have been too small and have used indices of magnetic field exposure that were too crude to provide any meaningful information.^{27,28} In the few occupational studies of magnetic field exposure and female breast cancer in which age-specific results have been presented, the association has been most pronounced at younger ages.^{22,24} Loomis *et al*²² reported a rate ratio of fatal breast cancer of 2.15 (95% CI = 1.16–3.96) for women ages 45–54 years, whereas for women above 54 years, the value was 1.19 (95% CI = 0.81–1.76). In a study by Coogan *et al*,²⁴ the odds ratio in the highest

exposure category was 1.84 (95% CI = 0.98–3.44) for premenopausal women and 1.32 (95% CI = 0.81–2.13) for postmenopausal women. Other occupational studies reported no risk elevation but did not examine age-specific effects.^{17,23,25} In a study evaluating the effect of electric blanket use, an association was indicated among both pre- and postmenopausal women.^{31–34} Daily use continuously throughout the night for 2–5 years, however, was associated with a greater effect than 10 years of use.³⁴ Studies of occupational exposure to radio-frequency fields have indicated a modest increase in breast cancer risk.^{44,45}

The occupational studies on male breast cancer and electromagnetic field exposure have generally been based on small numbers of cases.^{13–21} Several of them have indicated an association,^{13–18} but there are also studies in which no association was observed.^{19,20}

An oncogenic effect of melatonin on ER-positive breast cancer cells has been demonstrated,¹⁰ and 60-Hz magnetic fields have been shown to block this effect.⁴⁶ Our results indicated a higher relative risk for cases with ER-positive breast cancer, especially for younger women, but the number of cases in these analyses was small. We also found a protective effect for ER-negative breast cancer cases, but this finding was based on an even smaller number of cases. The analyses used a lower exposure cutpoint (0.1 μ T) than in the other analyses, largely because no control subject among younger women had exposure levels ≥ 0.2 μ T (four cases had exposures ≥ 0.2 μ T). The instability of the effect estimates prevents a firm conclusion regarding the possible modifying effect of ER status.

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