Residential Exposure to 60-Hertz Magnetic Fields and Adult Cancers in Taiwan

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We conducted a case-control study, using matching on date of birth, sex, and date of diagnosis, in northern Taiwan to evaluate the risks of adult leukemia, brain tumors, and female breast cancers in relation to residential exposure to 60-Hertz (Hz) magnetic fields. Cases were persons with newly diagnosed cancers reported to the cancer registry between 1987 and 1992, and controls were persons with cancers of sites other than those previously suspected of being associated with magnetic fields. Magnetic fields in the residences occupied by the study subjects at the time of diagnosis were estimated from high-voltage transmission lines. The results were based on the separate analysis of 870 cases of leukemia, 577 brain tumors, and 1,980 female breast cancers. We estimated the risk of leukemia among those exposed to magnetic fields of >0.2 microtesla (μT), relative to the risk among those exposed to fields of <0.1 μT; the odds ratio was 1.4 [95% confidence interval (CI) = 1.0–1.9]. For distance <50 meters relative to ≥100 meters, the relative risk was 2.0 (95% CI = 1.4–2.9). For brain tumors and female breast cancers, the odds ratios were close to unity. (Epidemiology 1997;8:25–30)

Keywords: magnetic fields, leukemia, brain tumors, breast cancer, risk factors, case-control study.

Studies of adult cancers in relation to residential exposure to magnetic fields have been neither as extensive nor as consistent as childhood and occupational studies in reporting an association between magnetic fields and increased cancer risks. Leukemia was positively associated with magnetic fields in three case-control studies.[1–3] Two other case-control studies[4,5] and two cohort studies[6,7] did not show such a link. Brain tumors and breast cancers have rarely been examined in these studies. We conducted the present investigation to evaluate the risks of leukemia, brain tumors, and female breast cancers in adults with elevated residential exposure to 60-Hertz (Hz) magnetic fields resulting from high-voltage transmission lines.

Subjects and Methods

Cases and Controls

We identified cases and controls from the National Cancer Registry of Taiwan, which has been in operation since 1979. Pathologically confirmed incident cancer patients are reported by 265 hospitals, including all medical centers and teaching hospitals nationwide. We selected cases and controls from all cancer patients 15 years of age or older who were registered between 1987 and 1992. Within the study period, 1,135 cases of leukemia [*International Classification of Diseases for Oncology* (ICD-O) codes 980–994], 705 brain tumors (ICD-O 191), and 2,407 female breast cancers (ICD-O 174) (between 1990 and 1992 only, since sample size was large enough) were newly diagnosed. Controls were cancer patients with a diagnosis other than cancers of the hematopoietic and reticuloendothelial systems (ICD-O 169), male breast (ICD-O 175), skin (ICD-O 173), ovary, fallopian tube, and broad ligament (ICD-O 183), and prostate gland (ICD-O 185). We excluded these cancers to avoid including among controls cancers potentially associated with magnetic field exposure.[8] For each case, we randomly selected and matched one control on date of birth (±5 years), sex, and date of diagnosis (±6 months). All study subjects were residents of one of the four administrative areas of northern Taiwan (Taipei city, Keelung, Taipei county, and Taoyuan) at the time of diagnosis.

After the selection was completed, we further examined the 4,247 pairs of study subjects (1,135 leukemia, 705 brain tumors, and 2,407 female breast cancers) on cancer diagnosis and residential address at time of diagnosis. We verified registry data against the information on hospital records and checked for possible duplicate registration. We replaced the selected controls when one or more of the following errors were noticed: missing information on address at the time of diagnosis; no pathologic confirmation in the file; or being selected more than once owing to duplicate registration. Among

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the cases, 42 (11 leukemia, 9 brain tumors, and 22 female breast cancers) had at least one of the preceding errors and were excluded, along with their controls. These exclusions reduced the number of pairs for leukemia, brain tumors, and female breast cancers to 1,124, 696, and 2,385, respectively.

Assessment of Residential Magnetic Field Exposure

Large-scale maps showing the location of each residence were available for 31 of the 45 districts (69%) in the study area. The maps were not identical in magnitude; scales ranged from 1:5,300 (1.89 mm = 10 m) to 1:10,000 (1.00 mm = 10 m). Unavailability of maps for the remaining 14 districts meant that exposure assessment for the subjects residing in those areas was impossible. The remaining numbers of cases/controls were 870/889, 577/552, and 1,980/1,880 for the groups of leukemia, brain tumors, and female breast cancers. The number of matched pairs preserved was 708 for leukemia, 455 for brain tumors, and 1,562 for female breast cancers.

The utility route maps of the Department of Transmission and Substation Project of Taiwan Power Company indicated that there were 121 high-voltage transmission lines operating in the study area between 1987 and 1992. These transmission lines were of five different types: 69 kilovolts (kV) with one circuit (N = 34), 69 kV with two circuits (N = 63), 161 kV with one circuit (N = 3), 161 kV with two circuits (N = 20), and 345 kV with two circuits (N = 1). There was no power line within 200 meters of the edge of the study area, indicating that magnetic fields of the residences occupied by the study subjects were unlikely to be affected substantially by exposure coming from transmission lines outside the boundaries of the study area.

The Department of Transmission and Substation Project supplied distance between wires, height of each wire above the ground, annual average and maximum loads on the lines from 1987 to 1992, current phase, and geographical resistivity of earth for the calculation of residential exposure. We determined the distance of each residence from the nearest transmission lines in stepwise fashion. The residence occupied by the subject at the time of diagnosis was first dotted on the residential map. We then sent these maps to the Department of Transmission and Substation Project, which generated, using computerized utility maps, utility route maps with identical scales. Using these utility route maps and residential maps, we were able to measure the distance between each residence and the nearest transmission lines to a precision of 10 meters. The residential magnetic fields were assessed at 1 meter above the floor. For apartments, we arbitrarily assumed the height between floors to be 3 meters. The subject's disease status was masked throughout the exposure assessment. We calculated the average and maximum residential magnetic fields using software created by Robert G. Olsen.[9]

Validation of Calculated Magnetic Fields

We selected 407 residences for validation. We measured magnetic fields in the selected residences with the EMDEX Electric and Magnetic Field Digital Exposure System.[10] All on-site measurements were performed between November 1994 and May 1995. Nearly all measurements were performed at a low-power condition (household power turned off). The indoor measurement was conducted over approximately 30–40 minutes, with a sampling time interval of 30 seconds, giving rise to approximately 70–80 readings for each residence. We compared the arithmetic mean of the measured magnetic fields with the concomitant fields calculated from the nearest transmission lines. With the results grouped into three categories [<0.1 microtesla (μT), 0.1–0.2 μT, >0.2 μT], the comparison showed a kappa of 0.64 [95% confidence interval (CI) = 0.50–0.78] between the two exposure estimates. The agreement increased to a kappa of 0.72 (95% CI = 0.62–0.82) when a 0.5 weight was assigned to allow for partial agreement. The kappa was 0.82 (95% CI = 0.79–0.86) when the analysis was restricted to those residences with both measured and calculated magnetic fields greater than 0.2 μT categorized with cutoff points of 0.5 and 1 μT.

Potential Confounders

Previous studies have shown an association between urbanization and certain types of cancer in Taiwan.[11] We used an index of urbanization that takes into consideration local population density, age, mobility, economic activity and family income, educational level, and sanitation facilities[12] to adjust for urbanization. Because it was a condition of access to the registry that study subjects not be interviewed, no other cancer risk factor information could be obtained directly from study subjects. We alternatively retrieved information on other potential confounders from questionnaires administered at the medical centers to some hospitalized patients or to their next of kin. This questionnaire covered demographic data (age, weight, and height), educational level, smoking, and previous x-ray exposure. Female patients were sometimes asked about reproductive history such as age at menarche, menopausal status, characteristics of menstrual cycles, parity, age at first delivery, and breastfeeding history. The above information was available for 2,288 subjects (1,115 cases and 1,173 controls) [reproductive factors were available for 1,096 subjects (612 cases and 484 controls)]. We explored the association between these cancer risk factors and residential magnetic field exposure among 1,173 controls (311, 203, and 659 for leukemia, brain tumors, and female breast cancers, respectively) to assess the potential for these variables to produce confounding.

Statistical Analysis

The measures of exposure were average and maximum residential magnetic fields and distance from residence to the nearest transmission lines for each subject for the year of cancer diagnosis. We calculated relative risk estimates for two exposure categories, >0.2 μT and 0.1–0.2 μT, relative to low exposure (<0.1 μT). We also calculated relative risk estimates for two distance

TABLE 1. Descriptive Characteristics of Cases and Controls by Cancer Types

	Leukemia				Brain Tumors				Female Breast Cancers			
	Case	%	Control	%	Case	%	Control	%	Case	%	Control	%
Age at diagnosis (years)												
<40	326	37.5	336	37.8	240	41.6	236	42.8	498	25.2	480	25.5
40–49	111	12.8	113	12.7	92	15.9	82	14.9	596	30.1	567	30.2
50–59	129	14.8	133	15.0	85	14.7	79	14.3	394	19.9	374	19.9
≥59	304	34.9	307	34.5	160	27.8	155	28.0	492	24.8	459	24.4
Sex												
Male	519	60.0	525	59.1	328	56.9	317	57.4				
Female	351	40.0	364	40.9	249	43.1	235	42.6	1,980	100.0	1,880	100.0
Year of diagnosis												
1987	156	17.9	104	11.7	109	18.9	90	16.3				
1988	123	14.1	114	12.8	97	16.8	72	13.0				
1989	145	16.7	140	15.8	96	16.6	90	16.3				
1990	145	16.7	126	14.2	87	15.1	100	18.1	559	28.2	672	35.7
1991	140	16.1	177	19.9	101	17.5	86	15.6	619	31.3	539	28.7
1992	161	18.5	228	25.6	87	15.1	114	20.7	802	40.5	669	35.6
Urbanization*												
I	478	54.9	495	55.7	299	51.8	287	52.0	1,198	60.5	1,042	56.4
II	259	29.8	252	28.4	198	34.3	176	31.9	508	25.7	561	29.8
III	133	15.3	142	15.9	80	13.9	89	16.1	274	13.8	277	14.8
Areas												
Taipei city	444	51.0	441	49.6	275	47.7	259	46.9	1,075	54.3	948	50.4
Keelung	56	6.4	66	7.4	37	6.4	39	7.1	114	5.8	108	5.7
Taipei county	305	35.0	308	34.7	221	38.3	205	37.1	664	33.5	674	35.9
Taoyuan	65	7.6	74	8.3	44	7.6	49	8.9	127	6.4	150	8.0
Total	870	100.0	889	100.0	577	100.0	552	100.0	1,980	100.0	1,880	100.0

* Urbanization I indicates the districts most urbanized.

exposure categories, 0–49 and 50–99 meters from transmission lines, relative to 100 meters. We also estimated the relative risks for those with exposure at ≥95th or ≥99th percentile of all controls for the three cancer groups.

The analyses further included the exploration of cell-specific, sex-specific, and age-specific odds ratios (ORs). We chose the median age among all controls from the three study groups (47 years) for the calculation of age-specific ORs.

We used multiple unconditional logistic regression analysis for the calculation of ORs with adjustment for age at time of diagnosis, sex, year of diagnosis, and urbanization.[13] Two-sided 95% CIs for ORs were based on maximum likelihood estimation of the logistic parameters.[14] We examined dose-response by fitting a model with a term for magnetic fields coded 1, 2, and 3, corresponding to the three exposure levels. We also performed a matched analysis of the intact matched pairs.

Results

Table 1 shows the distribution of study subjects by age at time of diagnosis, sex, year of diagnosis, level of urbanization, and district of residence. Since Taipei city and its metropolitan area were included within the boundary limits of the study area, a large proportion of the study participants (55%) lived in a highly urbanized environment. Table 2 shows the distribution of cases and controls according to distance from high-voltage transmission lines and levels of exposure to calculated residential magnetic fields. The proportions of controls who resided within 100 and 50 meters from the transmission lines were 12.9% and 6.6%, respectively. Some 9.9% of the controls had an exposure of ≥0.2 μT, and 5.6% had an exposure of ≥0.5 μT. The proportion of controls whose residences were located within 50 meters (6.6%) and the proportion located between 50 and 99 meters (6.3%) are almost identical, a finding that indicates that, in the study area, high-voltage transmission lines were not a deterrent to the construction or the location of houses.

Table 3 shows the odds ratios and the corresponding confidence intervals for leukemia, brain tumors, and female breast cancers in relation to the distance of the subject's address at time of diagnosis to the nearest transmission lines. The reference group for the calculation of the odds ratios is people whose residences were located at ≥100 meters from the lines. For people residing within 50 meters of the transmission lines, the odds ratio for leukemia was 2.0 (95% CI = 1.4–2.9), whereas, for brain tumors and female breast cancers, it was much lower (brain tumors: OR = 1.3, 95% CI = 0.8–2.1; female breast cancers: OR = 1.0, 95% CI = 0.8–1.3). At a distance between 50 and 99 meters from the power lines, the odds ratio for leukemia was elevated (OR = 1.5, 95% CI = 1.1–2.3) somewhat less than for those living in houses located within 50 meters.

From our comparison of the calculated field estimates with the measured magnetic fields, we found that, for values of ≥0.1 μT, the calculated fields were reliable, but for lower values, these estimates were blurred by local sources of magnetic fields. For that reason, we regrouped the exposure into three categories: <0.1 μT, 0.1–0.2 μT, and >0.2 μT. These categories permitted

TABLE 2. Distributions of Subjects by Distance from High-Voltage Transmission Lines and Estimated Residential Magnetic Fields

	Leukemia				Brain Tumors				Female Breast Cancers			
	Case	%	Control	%	Case	%	Control	%	Case	%	Control	%
Distance from high-voltage transmission lines (meters)*												
<25	66	7.6	30	3.4	27	4.7	18	3.3	93	4.7	69	3.7
25–49	23	2.6	18	2.0	18	3.1	14	2.5	63	3.2	70	3.7
50–99	71	8.2	49	5.5	40	6.9	51	9.2	143	7.2	112	6.0
100–199	96	11.0	102	11.5	65	11.3	68	12.3	181	9.1	196	10.4
≥200	614	70.6	690	77.6	427	74.0	401	72.7	1,500	75.8	1,433	76.2
Estimated residential magnetic fields (μT)†												
<0.01	620	71.3	683	76.8	424	73.5	397	71.9	1,503	75.9	1,417	75.4
0.01–0.099	106	12.2	93	10.5	59	10.2	68	12.2	146	7.4	173	9.2
0.1–0.199	47	5.4	40	4.5	23	4.0	24	4.4	107	5.4	94	5.0
0.2–0.499	29	3.3	30	3.4	34	5.9	29	5.3	92	4.6	84	4.5
≥0.5	68	7.8	43	4.8	37	6.4	34	6.2	132	6.7	112	5.9
Total	870	100.0	889	100.0	577	100.0	552	100.0	1,980	100.0	1,880	100.0

* Based on the subject's address at time of diagnosis.
† Calculated from annual average currents in transmission lines for the year of diagnosis.

comparisons with other studies. Table 4 gives the odds ratios for leukemia, brain tumors, and female breast cancers as well as for their main cell-specific types. For leukemia, the odds ratios were moderately elevated in the middle-exposure category (OR = 1.3, 95% CI = 0.8–1.9) and in the highest category (OR = 1.4, 95% CI = 1.0–1.9). For brain tumors and female breast cancers, the odds ratios were close to one. A trend test yielded a value of $P = 0.04$ for leukemia with increased exposure to magnetic fields. No trend was evident for either brain tumors or female breast cancers.

Analysis of leukemia subtypes indicated that the most elevated risk was observed for acute lymphoid leukemia in the exposure group >0.2 μT (OR = 1.7, 95% CI = 1.0–3.1). The odds ratios for the other subtypes vary between 0.3 and 2.8, reflecting some variability stemming from the small number of exposed subjects. Except for acute lymphoid leukemia, there is no indication of a trend with gradient of exposure among the leukemia subtypes. The odds ratios for astrocytoma, glioblastoma, and oligodendroglioma were either close to unity or unreliably decreased or elevated. For female breast cancers, we saw a moderate increase in risk of some malignant adenomas and adenocarcinomas (OR = 1.5, 95% CI = 0.7–3.2) in the highest-exposure group.

In a sex-specific analysis (not presented in tables), the odds ratio of leukemia for men was 1.4 (95% CI = 0.9–2.2), and for women 1.3 (95% CI = 0.8–2.2) in the exposure group >0.2 μT. For brain tumors, the odds ratio for men was 1.0 (95% CI = 0.6–1.6), and for women 1.3 (95% CI = 0.7–2.4). As for age-specific odds ratios, among those in the age group below median age (47 years), there was a slightly higher relative risk of leukemia (OR = 1.6, 95% CI = 1.0–2.5) than among people above median age (OR = 1.3, 95% CI = 0.8–2.0). The age-specific odds ratios were 0.8 below median age (95% CI = 0.5–1.4) and 1.5 above median age (95% CI = 0.9–2.5) for brain tumors; and 0.9 (95% CI = 0.7–1.2) and 1.2 (95% CI = 0.9–1.7), respectively, for female breast cancers.

Table 5 shows the odds ratios for exposure to both ≥95th percentile (0.59 μT) and ≥99th percentile (2.34 μT) of all controls for the three cancer groups, compared with exposure of <0.1 μT. At the ≥95th percentile, the odds ratio for leukemia was 1.8 (95% CI = 1.2–2.7), whereas the odds ratios for brain tumors (OR = 1.2, 95% CI = 0.7–2.0) and female breast cancers (OR = 1.1, 95% CI = 0.8–1.4) were barely elevated. Using the 99th percentile, the odds ratio for leukemia dropped to 1.3 (95% CI = 0.6–2.8), whereas the risk for brain tumors increased dramatically to 6.4 (95% CI = 0.8–53.5), and the odds ratio for

TABLE 3. Relative Risk Estimates* for Leukemia, Brain Tumors, and Female Breast Cancers by Distance from High-Voltage Transmission Lines

	Distance of Subject's Address to Nearest Transmission Lines (Meters)			
Diagnosis	0–49	50–99	≥100†	Total
Leukemia				
Cases	89	71	710	870
Controls	48	49	792	889
OR (95% CI)	2.0 (1.4–2.9)	1.5 (1.1–2.3)	1.0	
Brain tumors				
Cases	45	40	492	577
Controls	32	51	469	552
OR (95% CI)	1.3 (0.8–2.1)	0.8 (0.5–1.2)	1.0	
Female breast cancers				
Cases	156	143	1,681	1,980
Controls	139	112	1,629	1,880
OR (95% CI)	1.0 (0.8–1.3)	1.2 (0.9–1.5)	1.0	

* Relative risk estimates (odds ratios) were derived from the unconditional likelihood estimate of logistic regression coefficient with adjustment for age at diagnosis, year of diagnosis, sex (except for female breast cancers), and urbanization.
† Referent category.

TABLE 4. Relative Risk Estimates* for Leukemia, Brain Tumors, and Female Breast Cancers by Calculated Residential Magnetic Field Exposure in the Year of Diagnosis

	Exposure Group						
		0.1–0.2 μT			>0.2 μT		
Diagnosis	<0.1 μT (No.)	No.	OR	95% CI	No.	OR	95% CI
All leukemias†	726	47	1.3	0.8–1.9	97	1.4	1.0–1.9
ALL (9821)‡	101	8	1.5	0.7–3.2	17	1.7	1.0–3.1
AML (9861)	346	28	1.5	0.9–2.5	41	1.1	0.7–1.7
CLL (9823)	37	4	2.8	0.9–9.3	3	0.6	0.1–2.6
CML (9863)	138	2	0.3	0.1–1.2	22	1.5	0.9–2.6
Others	104	5	1.0	0.4–2.5	14	1.3	0.7–2.5
Controls	776	40			73		
	P for trend for all leukemias 0.04						
All brain tumors	483	23	0.9	0.5–1.7	71	1.1	0.8–1.6
Astrocytoma (9400–1, 9410–1, 9420–1)	149	4	0.6	0.2–1.8	16	0.8	0.5–1.5
Glioblastoma (9440–2)	113	8	1.3	0.5–2.9	19	1.1	0.6–2.0
Oligodendroglioma (9450–1)	26	3	2.8	0.8–10.4	2	0.6	0.1–2.5
Others	195	8	0.8	0.3–1.8	34	1.3	0.8–2.0
Controls	465	24			63		
	P for trend for all brain tumors 0.75						
All female breast cancers§	1,649	107	1.1	0.8–1.5	224	1.1	0.9–1.3
Group I	1,414	89	1.0	0.8–1.4	193	1.0	0.8–1.2
Group II	58	0	0		7	0.9	0.6–1.3
Group III	42	3	1.3	0.4–4.2	8	1.5	0.7–3.2
Others	135	15	1.7	0.9–3.1	16	0.9	0.5–1.6
Controls	1,590	94			196		
	P for trend for all breast cancers 0.31						

* Relative risk estimates (odds ratios) were derived from the unconditional likelihood estimate of logistic regression coefficient with adjustment for age at diagnosis, year of diagnosis, sex (except for female breast cancers), and urbanization.

† ALL = acute lymphoid leukemia; AML = acute myeloid leukemia; CLL = chronic lymphoid leukemia; CML = chronic myeloid leukemia.

‡ Numbers in parentheses are *International Classification of Diseases for Oncology* (ICD-O) 1987 codes.

§ Group I, ICD-O = 8500–3, 8510, 8512, 8520–2, 8530, 8540–3; Group II, ICD-O = 8010, 8020, 8032; Group III, ICD-O = 8140, 8170, 8200–1, 8210–1, 8260.

female breast cancers rose to 1.3 (95% CI = 0.7–2.2).

Matched analysis based on the original pairing yielded essentially the same results as the unmatched analysis.

Discussion

The present study provides additional evidence for a link between residential exposure to 60-Hz magnetic fields and the risk of leukemia in adults. Neither brain tumors nor female breast cancers show an increased risk with elevated residential exposure to magnetic fields. The analysis by cell-specific types of leukemia shows that the excess risk was concentrated in cases of acute lymphoid leukemia. A substantial increase in risk of brain tumors (OR = 6.4) was observed for subjects with very high exposure (2.34 μT), but this relative risk estimate was based on only 6 exposed cases and 1 exposed control.

In selecting our controls, we eliminated cancers potentially associated with magnetic fields, such as cancers of the hematopoietic and reticuloendothelial systems, male breast, skin, ovary, fallopian tube, broad ligament, and prostate gland cancers. As a consequence, our control series comprised largely lung and liver cancers among men and cervical cancers among women. As these cancers may be more prevalent among people from low socioeconomic status, cases and controls may have dissimilar socioeconomic status. Because magnetic field exposure from power lines is likely to be more common in lower-socioeconomic status groups (presumably, it is less attractive to live close to power lines), one would expect that this control selection would have tended to mask any positive association between magnetic field exposure and cancer (leukemia and female breast cancer). To evaluate the potential impact of the dissimilar socioeconomic status between the two underlying populations, we tested the association between education (a stable indicator of socioeconomic status in adults) and residential magnetic field exposure among the 1,137 (35%) controls for which information was available. We found no association.

The quality of the National Cancer Registry of Taiwan was addressed elsewhere.[15] Completeness of the registry was approximately 85% during the period between 1979 and 1991. Between 1984 and 1986, the proportion of erroneous diagnosis and addresses at time of diagnosis was 4.1% and 10.2%, respectively. The incomplete coverage of all incident cancers probably did not influence our results, since any selection in the cancers studied would have applied to the control cancers as well. The errors in cancer diagnosis and addresses at time of diagnosis may, however, have caused some misclassification of both disease and exposure status. We did verify data from the registry against data recorded on hospital reports and made corrections when appropriate.

The present study was based on the residence at time of diagnosis. It was not possible to obtain each subject's residential history, and therefore no cumulative exposure index could be calculated. As a result, our exposure assessment was subject to nondifferential misclassification. Nondifferential misclassification of exposure does not cause bias away from unity in the highest-exposure category.[16] Such bias may, however, account for near-null findings for both brain tumors and female breast cancers.

In the present study, we were unable to adjust for known risk factors for leukemia, brain tumors, or female breast cancers. Using the information available on education, smoking, x-ray exposure history (N = 1,173), and reproductive factors (N = 484), we observed that these variables were nearly equally distributed among the three exposure categories. We compared controls for whom these data were available with the remaining

TABLE 5. Relative Risk Estimates* for Leukemia, Brain Tumors, and Female Breast Cancers for Calculated Residential Magnetic Field Exposure at ≥95th† or ≥99th† Percentile of All Controls

Diagnosis and Exposure Group	No. of Controls	No. of Cases	OR	95% CI
Leukemia				
<0.1 μT	776	726	1.0‡	
≥95th percentile	38	65	1.8	1.2–2.7
≥99th percentile	12	15	1.3	0.6–2.8
Brain tumors				
<0.1 μT	465	483	1.0‡	
≥95th percentile	30	37	1.2	0.7–2.0
≥99th percentile	1	6	6.4	0.8–53.5
Female breast cancers				
<0.1 μT	1,590	1,649	1.0‡	
≥95th percentile	98	115	1.1	0.8–1.4
≥99th percentile	22	33	1.3	0.7–2.2

* Relative risk estimates (odds ratios) were derived from the unconditional likelihood estimate of logistic regression coefficient with adjustment for age at diagnosis, year of diagnosis, sex (excluding female breast cancers), and urbanization.
† 95th percentile = 0.59 μT; 99th percentile = 2.34 μT.
‡ Referent category.

controls with respect to the distribution of magnetic field exposure. For controls with information on potential confounders, 85.5% had an exposure <0.1 μT, 4.9% between 0.1 and 0.2 μT, and 9.6% >0.2 μT. The corresponding figures for the other controls were 85.3%, 4.8%, and 10.0%, respectively. Although indirect, this finding indicates little basis for confounding by uncontrolled risk factors.

There have been seven publications so far on the relation between adult leukemia and residential exposure to magnetic fields.[1–7] Three of them have suggested an elevated risk for leukemia.[1–3] The study by Feychting and Ahlbom[3] reported no excess risk of leukemia in relation to exposure at time of diagnosis, but a 50% increase in the risk for cumulative exposure during the 15 years preceding the diagnosis (exposure ≥2.0 μT-years). Their finding differs from our results, which show an association with exposure at time of diagnosis. One possible explanation for this difference is the low mobility of our study population. The population who have moved each year in northern Taiwan was around 5.4% between 1987 and 1992,[17] so that exposure estimated at time of diagnosis may have corresponded better to historical exposure in our study than in the Swedish study. The four studies[4–7] that did not show any elevated risk for leukemia had a noticeably low percentage of their population exposed to magnetic fields of >0.2 μT or small numbers of leukemia in the high-exposure category.

Of the four publications on adult brain tumors and residential exposure to magnetic fields,[3,4,6,7] only Wertheimer and Leeper[4] reported an association with wiring codes. Except for the study by Feychting and Ahlbom,[3] these studies suffered from inadequate size. The results from our study were generally consistent with the previous findings of no effect of magnetic field exposure at home on risk of brain tumors.

Few studies have been published on the association between female breast cancers and residential exposure to magnetic fields. Neither premenopausal[18] nor postmenopausal[19] breast cancers were observed to be associated with the use of electric blankets. Two retrospective cohort studies that have looked at the association between female breast cancers in regard to magnetic field exposure originating from electric substations and overhead power lines have yielded null results.[6,7] Our study did not find any excess risk of breast cancer among adult women with elevated magnetic field exposure at home.

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