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ORIGINAL ARTICLE

Residential exposure to electric power transmission lines and risk of lymphoproliferative and myeloproliferative disorders: a case–control study

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Abstract

Background: Studies have shown an association between electromagnetic fields and childhood leukaemia. The aim of this study was to determine whether there is an increased risk of lymphoproliferative disorders (LPD) or myeloproliferative disorders (MPD) associated with residence $\leq$300 m from high-voltage power lines.

Methods: Case–control study of 854 patients diagnosed with LPD or MPD (including leukaemia, lymphoma and related conditions) aged 0–94 years comprising all cases diagnosed in Tasmania between 1972 and 1980. Controls were individually matched for sex and approximate age at the time of diagnosis.

Results: Compared with those who had always lived >300 m from a power line, those who had ever lived within 50 m had an odds ratio (OR) of 2.06 (95% confidence interval 0.87–4.91) for developing LPD or MPD (based on 768 adult case–control pairs); those who had lived between 50 and 300 m had an OR of 1.30 (0.88–1.91). Adults who had lived within 300 m of a power line during the first 15 years of life had a threefold increase in risk (OR 3.23; 1.26–8.29); those who had lived within the same distance aged 0–5 years had a fivefold increase in risk (OR 4.74; 0.98–22.9). These associations were strengthened when analyses were repeated for 201 pairs with entirely Tasmanian residential histories.

Conclusion: Although recognizing that this study has limitations, the results raise the possibility that prolonged residence close to high-voltage power lines, especially early in life, may increase the risk of the development of MPD and LPD later.

Introduction

For more than two decades there has been a debate about the possible carcinogenicity of electromagnetic fields (EMF). In 1979 Wertheimer and Leeper reported that childhood cancers, including leukaemia, were more likely to develop in children who resided in homes with certain electrical wiring codes.[1] Since then numerous studies have investigated the correlation between occupational and residential exposures to EMF in a variety of settings and the development of cancer. A pooled analysis of magnetic fields and childhood leukaemia reported a doubling of risk associated with fields $\geq$0.4 μT.[2,3] However, the evidence on detrimental long-term health effects is far from conclusive and international guidelines for limiting exposure to EMF are based on possible short-term effects rather than longer-term disease risks such as cancer.[4]

EMF are generated by high-voltage electrical transmission lines among other sources and the risks, if any, associated with residential exposure to overhead power lines are a cause of public concern. A recent case–control

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study of childhood leukaemia and distance of home address at birth from the nearest high-voltage overhead power line found increased risks for those living within 600 m compared with those living more than 600 m from a power line.[5] Here we present a similar analysis of adult cancers. Although the number of cases is much smaller, lifetime addresses were available, allowing us to assess risks associated with residence close to power lines at any time in life.

Methods

Cases and controls

We analysed an existing dataset of all patients diagnosed with MPD and LPD in Tasmania between 1972 and 1980, with individually matched controls, in which complete residential histories were available.[6] Diagnoses included leukaemia, lymphoma, multiple myeloma, chronic myeloproliferative disorders and miscellaneous related disorders (Table 1). Cases were identified from histopathology and haematology laboratories throughout the state and ascertainment is thought to be virtually complete. Controls were selected from the electoral roll (registration is compulsory) using a series of random numbers and were matched on sex and age (to within 5 years). Five possible controls were selected and each was sent a letter of invitation to participate in the study. If more than one potential control responded, the first or the highest one of the five selected was chosen. If there was no response from all five, a second letter was sent. In the small number of cases where there was still no response, a suitable control was selected from among the redundant controls of other patients. Sometimes, particularly for patients born before 1900, it was not possible to match to within 5 years. In 19 (2%) cases the age difference exceeded 10 years. Patients were interviewed by one of a small number of trained interviewers. In a small number of instances where the patient had already died, interviews were carried out with relatives. Corresponding information was obtained from controls using a postal questionnaire.

Calculation of distance from power lines

The power grid in Tasmania comprising lines of 88, 110 or 220 kV, which was commenced in 1895, has remained remarkably stable overall and dates of commissioning of new cables, decommissioning and change in voltage are held by the Hydro-Electric Commission. Complete residential histories for cases and controls, from birth to the time of diagnosis, were linked to this information using maps supplied by the Lands Department, Hobart to determine lifetime residential proximity to power lines (of a period of 3 months or more). Where the distance was $\leq$300 m, exact distances were determined from a street atlas or by visiting the address if it was very close to the line. When necessary, additional information was sought with the assistance of Australia Post, maps and archives of the Tasmanian government.

Statistical methods

We carried out matched analyses using conditional logistic regression models to calculate odds ratios (OR) and 95% confidence intervals (CI). Results were controlled for socioeconomic status by coding jobs according to the Australian Standard Classification of Occupations to derive three broad socioeconomic categories.[7] For retired persons, last recorded job was used and for couples who both worked, the higher job code was taken. Fifteen pairs (<2%) were excluded because no such information was available, leaving 768 adult case–control pairs. Analyses were also controlled for occupational exposure by calculating the number of years in jobs previously found to have an increased risk – farming, foundry work, mining and female hairdressing.[6] We investigated 'number of addresses' as a possible confounding factor, as we found

Table 1 Diagnosis and the number of patients for each of the categories LPD/MPD

Diagnostic category	Diagnosis	Adults	Children	Total no. patients
LPD	Non-Hodgkin lymphoma	252	11	263
	Multiple myeloma	123	0	123
	Chronic lymphocytic leukaemia	87	0	87
	Hodgkin lymphoma	77	6	83
	Acute lymphoblastic leukaemia	8	39	47
MPD	Chronic myeloproliferative disorders	106	7	113
	Acute myeloid leukaemia	96	8	104
	Chronic myeloid leukaemia	34	0	34
	Total	783	71	854

LPD, lymphoproliferative disorders; MPD, myeloproliferative disorders.

that controls on an average reported fewer addresses than patients, but this way did not notably alter the results.

More cases than controls had resided only in Tasmania. As incomplete exposure assessment among controls could bias the results, analyses were repeated for the 201 adult pairs that had both lived exclusively in Tasmania.

Results

Patients and controls lived at a total of 9245 addresses and 7590 Tasmanian addresses were identified. Ninety-four patients and 64 controls had at least one address within 300 m of a power line, suggesting an unadjusted OR of 1.5 ($P = 0.01$). The classification of these patients and controls according to the closest they had ever lived to a power line is shown in Table 2. There is an overall trend for patients to have lived closer to a power line than controls (P for trend = 0.02 based on 854 case–control pairs).

Based on 768 adult case–control pairs, those who had ever lived ≤50 m from a power line experienced double the risk of developing LPD/MPD of the baseline group, who had always lived >300 m (OR 2.06, 95%CI 0.87–4.91) (Table 3). There was also an increased risk associated with having lived 51–300 m from a line (OR 1.30, 95%CI 0.88–1.91). When only Tasmanian pairs were considered, these risks increased. In both cases, the results were consistent with a decreasing risk across the exposure groups 0–50 m, 51–300 m and >300 m.

OR per year of residence also shows a dose–response relation (Table 3). The estimates suggest that compared with living >300 m from a line, every year lived ≤50 m from a line increased risk by 7% (−1 to 17%), whereas every year living between 51 and 300 m was associated with a 1% (−2 to 4%) increase in risk. When only Tasmanian pairs were considered the OR were increased.

There was also some evidence that risk increased with line voltage. Compared with never having lived within 300 m of a power line, exposure to lines of 88, 110 and 220 kV were associated with increases in risk of 33, 44 and 45% (not statistically significant). Again, when only Tasmanian pairs were considered the OR increased.

Table 2 Number of patients and controls at the closest distance ever lived to a power transmission line

Distance (m)	Patients n = 854 (%)	Controls n = 854 (%)	Total n = 1708 (%)
0–50	19 (2.2)	9 (1.1)	28 (1.6)
51–300	75 (8.8)	55 (6.5)	130 (7.6)
>300	760 (89.0)	790 (92.4)	1550 (90.8)

Table 3 Risk associated with ever having lived 0–50 m or 51–300 m from a power line compared with 'never' and per year of residence (based on 768 adult case–control pairs and restricted to 201 Tasmanian pairs)

		Ever having lived		Per year of residence	
	Distance (m)	OR†	95%CI	OR†	95%CI
All pairs	0–50	2.06	0.87–4.91	1.07	0.99–1.17
	51–300	1.3	0.88–1.91	1.01	0.98–1.04
	>300	1	NA	1	NA
Tasmanian pairs only	0–50	2.93	0.22–38.40	1.37	0.81–2.32
	51–300	1.69	0.77–3.69	1.03	0.98–1.08
	>300	1	NA	1	NA

†Adjusted for socioeconomic status and occupational exposure. CI, confidence interval; OR, odds ratio; NA, not applicable to baseline group.

Age at the time of exposure

Risks associated with having lived within 300 m of a power line (i) at any time in the first 15 years of life, (ii) at any time in the 15 years before diagnosis and (iii) ever, were compared with never having lived within 300 m of a power line by three separate models (Table 4). The results suggest that exposure to power lines is most important in the early years of life. The OR for living ≤300 m from a line between birth and 15 years of age was 3.23 (1.26–8.29) and increased when restricting the analysis to Tasmanian pairs only.

The effect of exposure (living ≤300 m from a power line) at an early age was further investigated by dividing childhood into 0–5 years and 6–17 years inclusively (Table 5). Patients and controls were categorized according to age at first exposure using these groups and those exposed after age 17 were included in the baseline, unexposed group. The estimated risk associated with having lived within 300 m of a power line up to and including age 5 was almost fivefold (OR 4.74, 95%CI 0.98–22.9). The

Table 4 Risk associated with having lived 0–300 m from a power line at different stages of life: three separate models comparing exposure at (i) 0–15 years of age, (ii) 15 years before diagnosis and (iii) ever with 'never' (based on 768 adult case–control pairs and restricted to 201 Tasmanian pairs)

	Time of exposure	OR†	95%CI
All pairs	0–15 years of age	3.23	1.26–8.29
	15 years before diagnosis	1.32	0.88–1.98
	Ever	1.4	0.98–2.00
Tasmanian pairs only	0–15 years of age	6.63	0.73–60.5
	15 years before diagnosis	1.63	0.66–4.03
	Ever	1.74	0.81–3.76

†Adjusted for socioeconomic status and occupational exposure. CI, confidence interval; OR, odds ratio.

Table 5 Risk associated with first having lived 0–300 m from a power line at 0–5 years or 6–17 years compared with '≥18 years or never' (based on 768 adult case–control pairs and restricted to 201 Tasmanian pairs)

	Age at exposure (years)	OR†	95%CI
All pairs	0–5	4.74	0.98–22.9
	6–17	2.31	0.83–6.43
	≥18 or never	1	NA
Tasmanian pairs only	0–5	9.41	0.87–101.42
	6–17	4.54	0.22–92.20
	≥18 or never	1	NA

†Adjusted for socioeconomic status and occupational exposure. CI, confidence interval; OR, odds ratio; NA, not applicable to baseline group.

risk was lower, but still increased for ages between 6 and 17 (OR 2.31, 95%CI 0.83–6.43). A test for trend across the three groups was highly significant ($P < 0.01$). When the analysis was restricted to Tasmanian pairs, the OR increased.

Results by diagnostic category

Risks were also assessed according to main diagnostic categories, namely LPD and MPD (Table 6). There was a marked increase in risk of development of an LPD in adulthood for subjects who resided close to power lines in childhood (OR 6.18, 95%CI 1.37–27.90).

Socioeconomic status

The highest socioeconomic group was taken as baseline. The categorical variables representing the lower two socioeconomic groups had consistently increased OR in a dose–response order – approximately 1.6 and 1.7 ($P < 0.01$). When considering Tasmanian pairs only, these OR increased to approximately 2.1 and 2.8 ($P \leq 0.01$).

Table 6 Risk associated with having lived 0–300 m from a power line at different stages of life: three separate models comparing exposure at (i) 0–15 years of age, (ii) 15 years before diagnosis and (iii) ever with 'never' for LPD (based on 538 adult case–control pairs) and MPD (based on 230 adult case–control pairs)

Diagnosis	Time of exposure	OR†	95%CI
LPD	0–15 years of age	6.18	1.37–27.90
	15 years before diagnosis	1.18	0.76–1.84
	Ever	1.33	0.89–1.99
MPD	0–15 years of age	1.69	0.45–6.37
	15 years before diagnosis	2.29	0.80–6.59
	Ever	1.67	0.77–3.61

†Adjusted for socioeconomic status and occupational exposure. CI, confidence interval; LPD, lymphoproliferative disorders; MPD, myeloproliferative disorders; OR, odds ratio.

Occupational exposures

The OR associated with the number of years in a job considered to be 'high risk' was consistent across all analyses, suggesting an increase in risk of 2% for every year of occupational exposure ($P < 0.01$). This did not change when considering Tasmanian pairs only.

Discussion

Whether exposure to electric power transmission lines predisposes to cancer, particularly leukaemia and related disorders, is highly controversial. We have looked at the question from a life course perspective, making use of a unique dataset that included lifetime addresses. We found that adults who had lived within 50 m of a line had an OR of 2.06 (95%CI 0.87–4.91) for developing LPD or MPD whereas those who had lived between 50 and 300 m had an OR of 1.30 (0.88–1.91), compared with those who had always lived >300 m from a line.

Possible explanations for findings

Although the controls in this study were selected from the general population by a process using random numbers and were matched by age and sex, some significant differences were found between cases and controls. Controls were more likely than patients to have been born interstate or overseas and on average reported slightly fewer addresses. When we reanalysed a subgroup, where both the patient and control had never resided outside Tasmania, the observed association between residence close to electric power transmission lines and MPD/LPD was consistently strengthened. However, bias could have arisen through non-response from potential controls and through different methods of obtaining residential histories for cases (interview) and controls (postal questionnaire).

Our finding a risk of MPD/LPD associated with residential exposure to power lines does not necessarily mean that it is either the lines themselves or the electrical or magnetic fields caused by the lines that are responsible for the increased risk. Persons who live close to power lines tend to be from lower socioeconomic groups. Although we attempted to control for socioeconomic status and occupational exposure, our methods were limited by the available data.

The increasing body of evidence linking exposure to high-voltage power lines with the development of certain cancers is not supported by laboratory experiments[8] although experiments using magnetic fields much stronger than those measured in epidemiological studies have found interactions with known carcinogens.[9] Our results

suggest that the link may be greater with exposure in early life (age $\leq$5 years), implying that animal experiments should be repeated on newborns and *in utero*. Other studies have shown that the characteristic chromosome translocations of childhood leukaemia commonly arise prenatally, presumably during fetal haematopoiesis.[10] Although prenatal exposure was not recorded in this study, we note that eight patients but only one control recorded residential exposure to EMF at the time of birth.

The variation of magnetic field strength with distance is complex and there is disagreement in the published reports as to the distance from power lines at which EMF exert biological effects. According to previous studies, we considered those who lived more than 300 m from a power line as unexposed.[11,12] Field strength is proportional to $1/d$ radially from a single wire conductor, but in the case of overhead power lines, this is complicated by the fact that differently phased alternating current supplies are carried by parallel wires. The nature of the decrease in magnetic field with distance away from the line therefore depends on the configuration of the lines, but it has been suggested that the most likely correlation for high-voltage transmission lines is inverse square.[13] It has also been suggested that duration of continuous exposure is more important than the strength of exposure.[1] We calculated an 'exposure index' (voltage (kV) $\times$ duration of exposure (years)/distance $(m)^2$) in which exposures from several addresses and from multiple lines could be easily combined. (Note that line voltage was used as a proxy for magnetic field as the electrical current flowing through a power line varies from location to location and over time at the same location.) We found that this did not explain the data as well as the simpler models based on categorical distance (0–50, 51–300 and >300 m) and given that the model is harder to interpret, results are not presented. It is, however, possible that EMF exert an effect at distances of more than 300 m, particularly if field strength is assumed to be proportional to $1/d$. A recent study of residential exposure found evidence of an association between childhood leukaemia and the reciprocal of distance from high-voltage power lines and reported increased risks at distances of up to 600 m.[5] Also relevant is evidence that electric fields may be more important than magnetic fields, perhaps because of ionized air particles, and that high concentrations of ionized particles may be detected up to several hundred metres from high-voltage power lines.[14,15]

In this study we have only taken into account possible effects of residential exposure to EMF, with a crude adjustment for certain occupational exposures. In everyday life there are many other sources of EMF. However, a recent paper from Sweden found that for subjects living <50 m from a transmission line, exposure at home contributed approximately 80% of the total magnetic field exposure.[16] Thus confounding from other sources of EMF exposure is unlikely to dilute the results significantly.

An important question is whether our pooling of cases of differing diagnoses is justified. Modern epidemiological studies tend to be restricted to single diagnosis. Nonetheless, there are many historical and biological overlaps within and between the various diagnostic categories we have studied and the latest classification system retains the broad groupings of LPD and MPD.[17] There is considerable evidence that LPD and MPD share predisposing or aetiological factors.

Conclusion

Although we studied MPD/LPD cases from the whole of Tasmania (population 450 000) over a 9-year period, the number of subjects available for analysis was small and this makes our results somewhat imprecise. Nevertheless, OR consistently suggested a dose–response effect, whether the exposure was expressed in terms of distance from a line, years of exposure or line voltage. The greatest risk of all was an OR of 4.7 (1.0–22.9) in patients who developed an MPD/LPD in adulthood, having been exposed to EMF in the first 5 years of life and an OR of 6.2 (1.4–27.9) in patients who developed an LPD in adulthood, having been exposed in childhood. There are numerous precedents for our findings that the effects of exposure to a carcinogen may be delayed and that young children may be most vulnerable. Survivors of atomic bombs have shown an increased risk of developing a wide variety of cancers, including MPD/LPD, up to 60 years after the event.[18] An *in utero* origin for chromosomal translocations associated with several forms of leukaemia has been shown.[19]

Despite the limitations of this study, the associations we report are consistent with other similar but larger studies and our novel finding that the risks of adult leukaemia and lymphoma are most strongly associated with early childhood exposure to high-voltage power lines deserves further study at both the population and laboratory levels.[5]

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