Adult mortality from leukemia, brain cancer, amyotrophic lateral sclerosis and magnetic fields from power lines: a case-control study in Brazil

Mortalidade por leucemia, câncer de cérebro e esclerose lateral amiotrófica em relação a campos magnéticos: estudo do tipo caso-controle no Brasil

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Abstract

Recent publications renewed interest in assessing potential health risks for subjects living close to transmission lines. This study aimed at evaluating the association of both distance of home address to the nearest overhead transmission line and of the calculated magnetic fields from the power lines and mortality from leukemia, brain cancer, and amyotrophic lateral sclerosis. We carried out a death certificate based case-control study accessing adult mortality in the Metropolitan Region of São Paulo, in Brazil. Analysis included 1,857 cases of leukemia, 2,357 of brain cancer, 367 of amyotrophic lateral sclerosis, and 4,706 as controls. An increased risk for mortality from leukemia among adults living at closer distances to transmission lines compared to those living further then 400 m was found. Risk was higher for subjects that lived within 50 m from power lines (OR=1.47; 95% CI=0.99-2.18). Similarly, a small increase in leukemia mortality was observed among adults living in houses with higher calculated magnetic fields (OR=1.61; 95% CI=0.91-2.86 for those exposed to magnetic fields >0.3 μT). No increase was seen for brain tumours or amyotrophic lateral sclerosis. Our findings are suggestive of a higher risk for leukemia among subjects living closer to transmission lines, and for those living at homes with higher calculated magnetic fields, although the risk was limited to lower voltage lines.

Keywords: Electromagnetic fields. Leukemia. Brain cancer.

Resumo

Os estudos avaliando riscos à saúde da exposição a campos magnéticos têm apresentado resultados controversos. Duas revisões recentes apontam a necessidade de mais investigações sobre o tema. O objetivo deste trabalho foi avaliar o risco de mortalidade por leucemia, câncer de cérebro e esclerose lateral amiotrófica em adultos em relação à exposição residencial a campos magnéticos gerados por linhas de transmissão. Foi realizado um estudo do tipo caso-controle de base populacional utilizando dados do sistema de informação de mortalidade na Região Metropolitana de São Paulo, entre 2001 e 2005. O risco foi avaliado em relação à distância das residências para as linhas de transmissão e para o campo magnético calculado em cada residência. Foram incluídos no estudo 1.857 casos de leucemia, 2.357 de câncer de cérebro e 367 de esclerose lateral amiotrófica, além de 4.706 controles. Encontrou-se um risco aumentado para leucemia em adultos morando mais perto das linhas de transmissão em comparação àqueles morando a mais do que 400 m. O maior risco foi entre os que moravam a até 50 m da linha (OR=1,47; IC95%=0,99-2,18). Também foi encontrado risco para pessoas morando em casas expostas ao maior campo magnético (OR=1,61; IC95%=0,91-2,86, para campos magnéticos >0,3 μT). Não foi encontrado aumento para tumores cerebrais ou esclerose lateral amiotrófica. Nenhum dos resultados foi estatisticamente significante. Os resultados sugerem aumento no risco de mortalidade por leucemia entre adultos expostos a campos magnéticos, mas os resultados devem ser interpretados com cautela, uma vez que todos os intervalos de 95% confiança englobavam o risco nulo.

Palavras-chave: Campos eletromagnéticos/efeitos adversos. Leucemia. Neoplasias do sistema nervoso central. Estudo de caso-controle.

Introduction

Since Wertheimer and Leeper (1979) published results showing an association between childhood cancer and exposure to electromagnetic fields[1], there has been considerable scientific research to examine a possible association between residential and occupational exposure to extremely low-frequency magnetic field (ELF-MF) and the development of cancer and other diseases[2].

Despite of all scientific effort, controversy remains. Particularly problematic is a lack of a robust biological mechanism at low exposure levels, which could lead to the disease development[3]. The International Agency for Research on Cancer classified ELF-MF exposure as "possibly carcinogenic" to humans[4], largely based on the results of two pooled analyses reporting an increase in childhood leukemia risk associated with residential exposure to ELF-MF greater than 0.3 to 0.4 μT[5,6].

Investigation of ELF-MF health effects in adults has focused on cancers, as well as on reproductive disorders and neurodegenerative diseases[2]. Data on residential exposure and health risks to adults are sparse, since most studies of adults focused on occupational exposures[2,7].

Two recent comprehensive reviews on ELF-MF and adult leukemia and brain cancer concluded that the overall evidence for an association between ELF-MF and the risk of these diseases remains inadequate[2,8]. Regarding neurodegenerative diseases, particularly amyotrophic lateral sclerosis (ALS), further studies are needed to evaluate their link to ELF-MF exposure[8].

Exposure assessment is a major challenge in most studies, and different surrogates of the true exposure are used to assess residential exposure[9]. Recent developments in Geographic Information Systems have allowed a greater precision in estimating residential exposure to ELF-MF from high-voltage power lines. ELF-MF fields in homes arise mainly from low-voltage distribution wiring, house wiring

and grounding, and domestic appliances. For homes located close to high-voltage overhead transmission lines, however, these lines are likely to be the main source of ELF-MF[9].

We evaluated the association between distance of home address to the nearest overhead transmission line, and we calculated ELF-MF from these power lines and adult mortality from leukemia, brain cancer, and ALS in the Metropolitan Region of São Paulo, in Brazil (MRSP).

Methods

We carried out a death certificate based case-control study in the MRSP, which encompasses 39 municipalities, including the city of São Paulo – the largest city in South America. It includes a large urban conglomerate, with a population of approximately 20 million people and high demographic density (*circa* 2479.6 people/km^2)[10], and an extensive grid of overhead high-voltage power lines, with approximately 2,571 km of transmission lines.

Cases and controls selection

We included all deaths from leukemia (International Classification of Diseases Tenth Revision – ICD 10, C91-95), brain cancer (ICD 10 C71) and ALS (ICD 10 G12.2), which occurred in the MRSP in 40 year-adults or older, during the period from 2001 to 2005.

Controls were randomly selected from deaths from all other causes, except from those that had been suggested to be associated with ELF-MF. The excluded cases were: breast cancer (ICD 10 C50), prostate cancer (ICD 10 C61), cancer of the ovaries (ICD 10 C56), lymphomas (ICD 10 C81-C90), neurodegeneratives diseases (ICD 10 G10-G13, G20, G23, G30-G32, G35-G40), suicides (ICD 10 X60-X84), ischemic heart diseases (ICD 10 I20-I25), arrhythmias (ICD 10 I44-I49), and cerebrovascular diseases (ICD 10 I60-I69).

Subjects were identified from two different databases: for the city of São Paulo, data were extracted from the city's official mortality database. Data from the other 38 municipalities in the MRSP came from the State of São Paulo official database. Both databases are considered very reliable[11], and they are responsible for processing data from all deaths of residents of the MRSP. They include all information stated on the death certificate: age, gender, address, main cause of death (coded according to ICD 10), race, years of education, and marital status.

Data on cases and controls strictly in the city of São Paulo were used in a previous case-control study[12], and they were individually matched. Data for the other 38 cities in the MRSP were specifically collected for this study, and frequency matching was used. Cases and controls were matched by age group (five-year categories), gender, and city of residency. Individuals living in the city of São Paulo were further matched by district of residency in an attempt to control for socioeconomic disparities within the city.

For randomization, databanks of cases and controls were each divided into subgroups of the matching criteria (e.g. case subgroup of males, from 40 to 44 years-old, living in São Paulo; control subgroup of males, from 40 to 44 years-old living in São Paulo, and so on). Then, a random number was generated for each subject in all subgroups of controls, using an ordinary computer software. Subjects were assorted in numerical crescent order within its subgroup, and the first subjects in all subgroups were selected until we reached the needed number of controls by subgroup of matching criteria.

To check if excluding deaths from several causes that had been suggested to be associated with ELF-MF as possible controls could have led to selection bias, the final dataset of eligible controls in the city of São Paulo was compared to the total deaths (except cases) in the original register, and no significant differences were observed.

Exposure assessment

We assessed exposure both through calculation of ELF-MF in the subjects' houses and distances between houses and closest transmission line. We looked at all overhead power lines of 88, 138, 230, 345, and 440 kV in the MRSP. Data on transmission lines and substations were gathered from the electricity companies. Data included historical information on phasing, tower and substation locations, number of circuits, construction and load for each year, and other related information.

Cases and controls were combined into a single dataset, and data were geo-coded by a team blinded to the 'case' or 'control' status. For geo-coding, the subjects' addresses at time of death were associated with the digital cartographic basis of the MRSP. An address was geo-coded in relation to the axis of the street, assuming a mean width of 10 m for the streets, and a distance of 8 to 15 m from the dwelling's front door to the street axis. The shortest distance from homes to the nearest transmission line was then determined.

We applied a software that used layout and technical information from each power line to calculate the magnetic induction in μT in each dwellin. Details on calculation methods and results are published elsewhere[13]. Magnetic field calculation was done blindly to the case and control status.

Statistical analysis

The independent variable "distance from homes to the nearest transmission line" was divided into four categories, using cut points similar to those used in previous studies for ease of comparison. Dwellings located 400 m or further from transmission lines constituted the Reference Group (at distances beyond 200 m, the ELF-MF from transmission lines were thought not to be important).

Similarly, calculated ELF-MF was divided into three categories based on previous studies, and the Reference Group consisted of MF ≤0.1 μT.

We used unconditional logistic regression to calculate the Odds Ratio (OR) and 95% confidence intervals for the risk of death for the selected causes in relation to distance to transmission lines and calculated ELF-MF. Sociodemographic variables were assessed as possible confounders in multivariate models.

Ethics approval

This paper was approved by the Research Ethics Committee of the School of Medicine, University São Paulo.

Results

We identified 3,212 deaths from leukemia, brain cancer, and ALS in the city of São Paulo. The same number of individuals was randomly selected to compose the Control Group, resulting in a database of 6,424 individuals. During geo-coding, there was a loss of 100 subjects (1.6%), 61 (0.9%) of them being cases, and 39 (0.6%), controls. These losses were due to incomplete addresses in the original database, precluding their geo-coding. For each non geo-coded event, its matched case or control was also excluded and we ended up with 6,224 individuals included in the study for the city of São Paulo. This figure represents 97% of the initial database.

For the other 38 cities in the MRSP, we identified 1,778 cases and 1,778 controls. After the geo-coding process, 493 subjects (13.9%) could not be geo-coded due to incomplete addresses in the original database. Among these, there were 309 (8.7%) cases and 184 (5.2%) controls. The difference between rates of losses in geo-coding of cases and controls seemed to be entirely due to chance, and they were contrary to what would be expected since patients dying from leukemia, brain cancer, and ALS deaths are more likely to have been assisted by a doctor and have more complete death certificates.

At total, 9,287 subjects were included in the study (4,581 cases and 4,706 controls). Distribution of cases and controls according to the cause of death is shown in Table 1.

Cases were from 40 to 99 years-old (standard deviation – SD: 13 years-old) and age of controls ranged between 40 and 106 years-old (SD=13 years-old). Distribution of cases and controls according to age group and gender revealed that matching was successful (data not shown).

Cases and controls were not equally distributed according to sociodemographic characteristics, as shown in Table 2. Logistic regression analysis showed that non-whites had decreased risk for developing the outcomes of interest. Years of education was also associated with the outcomes of interest. All categories had increased risk when compared to those without any education, and there was a trend of the risk to be higher with higher education (data not shown).

We found a small increase in risk of leukemia for subjects living in homes exposed to higher calculated ELF-MF, although estimates were imprecise (Table 3).

We found an increase in risk for leukemia mortality for people living closer to transmission lines, and there was a slight trend of increasing risk with shorter distances (Table 4). We repeated the adjusted analysis, including age group in the model, and results did not materially change (data not shown).

For brain cancer and ALS there was no indication of or consistency in risk. Adjusting for sociodemographic factors did not materially change results (Table 4).

For each diagnostic group, we also carried out an analysis stratified by transmission lines voltages. The association was limited to lower voltages: only houses located in the proximities of transmission lines of up to 200 kV showed an increased risk for death from leukemia, among subjects living closer to the transmission line, and risk was higher for shorter distances. For higher voltages (>200 kV) there was no association, but the number of cases of people living next to these higher voltages transmission lines was much smaller, as can be seen from the resulting larger 95% CI. Results are shown in Table 5. For brain cancer and ALS, no consistent associations were found for either voltage category (data not shown).

Discussion

An increased risk for mortality from leukemia among adults living at closer distances to transmission lines compared to those living further than 400 m was found. Risk was higher for subjects that lived within 50 m from transmission lines (OR=1.47;

Table 1 - Frequency of cases and controls according to death cause, in the Metropolitan Region of São Paulo, from 2001 to 2005

Tabela 1 *- Total de casos e controles de acordo com a causa de morte - Região Metropolitana de São Paulo, 2001 – 2005*

Cases			Controls		
Death cause (ICD 10)	n	%	Death cause (ICD 10)	n	%
Leukemia (C91 – C95)	1857	40.5	Cancer[a] (C00-D48)	1194	25.4
			Cardiovascular disease[a] (I00-I99)	877	18.6
			Respiratory disease (J00-J99)	802	17.0
Brain cancer (C71)	2357	51.5	Digestive system diseases (K00-K99)	451	9.6
			Metabolic diseases (E00-E99)	352	7.5
			Infectious diseases (A00-B99)	296	6.3
ALS (G122)	367	8.0	External causes[a] (V00-Y99)	297	6.3
			Other[a]	437	9.3
Total	4581	100		4706	100

ICD 10: International Classification of Diseases; ALS: amyotrophic lateral sclerosis.[a] Except for death from breast cancer (ICD 10 C50), prostate cancer (ICD 10 C61) ovaries cancer (ICD 10 C56), lymphomas (ICD 10 C81-C90), neurodegeneratives diseases (ICD 10 G10-G13, G20, G23, G30-G32, G35-G40), suicides (ICD 10 X60-X84), ischemic heart diseases (ICD 10 I20-I25), arrhythmias (ICD 10 I44-I49), and cerebrovascular diseases (ICD 10 I60-I69).

Table 2 - Distribution of cases and controls according to race, marital status and schooling, in the Metropolitan Region of São Paulo, from 2001 to 2005

***Tabela 2** - Distribuição de casos e controles de acordo com raça, estado civil e escolaridade – Região Metropolitana de São Paulo, 2001 – 2005*

	Controls	Brain cancer	Leukemia	ALS
	n (%)	n (%)	n (%)	n (%)
Race*				
White	3495 (74.3)	1902 (80.7)	1490 (80.2)	300 (81.7)
Black	253 (5.4)	73 (3.1)	70 (3.8)	12 (3.3)
Asian	105 (2.2)	41 (1.7)	31 (1.7)	8 (2.2)
Mixed	647 (13.7)	256 (10.9)	186 (10.0)	28 (7.6)
Indigenous	1 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Unknown	205 (4.4)	85 (3.6)	80 (4.3)	19 (5.2)
Marital status*				
Single	935 (19.9)	321 (13.6)	210 (11.3)	47 (12.8)
Married	2192 (46.6)	1330 (56.4)	1036 (55.8)	209 (56.9)
Widowed	1160 (24.6)	485 (20.6)	469 (25.3)	77 (21.0)
Divorced	309 (6.6)	165 (7.0)	102 (5.5)	26 (7.1)
Consensual marriage	31 (0.7)	25 (1.1)	15 (0.8)	1 (0.3)
Unknown	79 (1.7)	31 (1.3)	25 (1.3)	7 (1.9)
Schooling (years completed)*				
None	440 (9.3)	157 (6.7)	104 (5.6)	16 (4.4)
1-3	1049 (22.3)	540 (22.9)	401 (21.6)	75 (20.4)
4-7	1122 (23.8)	560 (23.8)	450 (24.2)	100 (27.2)
8-11	579 (12.3)	345 (14.6)	300 (16.2)	54 (14.7)
12 and over	416 (8.8)	342 (14.5)	237 (12.8)	64 (17.4)
Unknown	1100 (23.4)	413 (17.5)	365 (19.7)	58 (15.8)

ALS: amyotrophic lateral sclerosis; *p<0.001 (McNemar's test).

Table 3 - Odds Ratio and 95% confidence interval for leukemia and brain cancer in relation to calculated extremely low-frequency magnetic fields, in the Metropolitan Region of São Paulo, from 2001 to 2005[a]

***Tabela 3** - Odds ratio e Intervalo de 95% de Confiança para leucemia e câncer de cérebro em relação aos campos magnéticos calculados – Região Metropolitana de São Paulo, 2001 – 2005*

EMF-MF	Controls	Leukemia			Brain cancer			ALS		
(μT)	n	n	OR	95% CI	n	OR	95% CI	n	OR[c]	95% CI
≤0.1 [b]	4629	1818	1	-	2323	1	-	366	1	-
>0.1; ≤0.3	31	15	1.34	0.65 to 2.73	12	1.13	0.5 to 2.30	0	-	-
>0.3	46	24	1.61	0.91 to 2.86	22	1.16	0.6 to 2.07	1	-	-

EMF-MF: extremely low-frequency magnetic fields; ALS: amyotrophic lateral sclerosis; OR: Odds Ratio; CI: confidence interval; [a] OR were adjusted for race, schooling and marital status; [b] Reference group; [c] could not be computed due to small number of cases.

95%CI=0.99-2.18). However, risk was mostly limited to those living close to lower voltage lines. Similarly, we found a small increase for leukemia mortality among adults living in houses exposed to higher calculated ELF-MF, although estimates were imprecise due to the small numbers of highly exposed.

No increase in risk was observed for brain cancer or ALS.

There is no obvious source of bias in the selection of subjects. We included all deaths from leukemia, brain cancer, and ALS occurring in the MRSP in the study period. These outcomes were chosen because they were associated with ELF-MF exposure in previous studies and for them mortality data is unlikely to differ substantially from incidence.

Table 4 - Estimated risks for leukemia, brain cancer, and amyotrophic lateral sclerosis according to the distance from houses to the nearest transmission line, in the Metropolitan Region of São Paulo, from 2001 to 2005
Tabela 4 *- Riscos estimados para leucemia, câncer de cérebro e esclerose lateral amiotrófica de acordo com a distância das casas para a linha de transmissão mais próxima – Região Metropolitana de São Paulo, 2001 – 2005*

Distance (meters)	n	OR	95% CI	OR[a]	95% CI
Leukemia					
>400 (Reference Group)	1518	1	-	1	-
>200; ≤400	151	0.93	0.77 to 1.13	0.88	0.70 to 1.11
>100; ≤200	87	1.13	0.88 to 1.47	1.07	0.79 to 1.44
>50; ≤100	46	1.19	0.83 to 1.69	1.08	0.71 to 1.64
≤50	55	1.43	1.03 to 2.01	1.47	0.99 to 2.18
Brain cancer					
>400 (Reference Group)	1949	1	-	1	-
>200; ≤400	200	0.97	0.81 to 1.15	0.97	0.79 to 1.19
>100; ≤200	112	1.14	0.90 to 1.45	1.19	0.91 to 1.55
>50; ≤100	53	1.07	0.76 to 1.50	1.08	0.74 to 1.59
≤50	43	0.88	0.61 to 1.26	1.10	0.74 to 1.64
Amyotrophic lateral sclerosis					
>400 (Reference Group)	308	1	-	1	-
>200; ≤400	37	1.13	0.79 to 1.61	1.24	0.83 to 1.86
>100; ≤200	17	1.10	0.66 to 1.82	1.14	0.65 to 2.02
>50; ≤100	3	0.38	0.12 to 1.22	0.49	0.15 to 1.56
≤50	2	0.26	0.06 to 1.05	[b]	[b]

OR: Odds Ratio; CI: confidence interval; [a] adjusted for race, schooling and marital status; [b] could not be computed due to small number of cases.

Table 5 - Frequency, Odds Ratios, and 95% confidence intervals for leukemia in relation to distance from homes to nearest transmission lines according to transmission lines voltages, in the Metropolitan Region of São Paulo, from 2001 to 2005
Tabela 5 *- Total de casos, Odds ratio e Intervalos de 95% de Confiança para leucemia em relação à distância das casas para a linha de transmissão mais próxima, de acordo com a voltagem das linhas – Região Metropolitana de São Paulo, 2001 – 2005*

Distance (meters)	n	OR	95% CI	OR[a]	95% CI
TL <200 kV					
>400 (Reference Group)	1367	1	-	1	-
>200; ≤400	136	0.97	0.79 to 1.19	0.91	0.71 to 1.17
>100; ≤200	81	1.23	0.94 to 1.62	1.16	0.85 to 1.59
>50; ≤100	42	1.34	0.92 to 1.96	1.18	0.75 to 1.85
≤50	50	1.50	1.05 to 2.14	1.50	0.98 to 2.28
TL >200 kV					
>400 (Reference Group)	151	1	-	1	-
>200; ≤400	15	0.72	0.40 to 1.31	0.69	0.34 to 1.42
>100; ≤200	6	0.58	0.24 to 1.42	0.45	0.13 to 1.57
>50; ≤100	4	0.58	0.19 to 1.72	0.57	0.16 to 2.07
≤50	5	1.03	0.37 to 2.92	1.32	0.43 to 4.09

OR: Odds Ratio; CI: confidence interval; [a] Adjusted for race, schooling and marital status.

We used official mortality databases for the City and State of São Paulo, which are thought to be complete[11], and it is not probable that registration of death certificates would be affected by proximity to transmission lines. Controls were randomly selected from the same databases and were matched for sex, age group, and city or district of residency.

No participation of cases or controls was required, therefore the possibility of selection or recall bias is minimal. We were

able to include 91.8 and 94.3% of eligible cases and controls, respectively. Losses of eligible subjects were small and due only to incompleteness of addresses in the original database precluding their geo-coding. As compared to subjects, whose addresses were successfully geo-coded, cases and controls that were not included in the study had similar distribution for age and gender, but higher proportion of black and mixed races and of less educated individuals. A possible explanation for this is due to the fact that in Brazil both these races area associated with lower socioeconomic status and people from lower socioeconomic status frequently live in slums or 'non-official addresses'.

Similar to other studies, our cases were more likely to be white and better educated[14-16]. Cases were also more likely 'not single'.

To check if any differences in the design, data quality or population characteristics might have influenced the results, we analyzed data separately for the city of São Paulo and for the other 38 cities in the MRSP. Results were materially the same (data not shown).

We had to rely on mortality, as cancer incidence records for the MRSP are not so complete when it comes to address information, which was required for this study. Using mortality instead of morbidity might introduce some bias. However, we think such bias is unlikely to be substantial due to poor prognosis of adult leukemia, brain cancer, and ALS. We analysed all leukemia subtypes as a group, which might introduce some bias due to different prognosis and different aetiology across these subtypes. Unfortunately, small numbers do not allow an analysis by subtypes.

Distances were blindly calculated to the case or control status. Cases and controls were geo-coded according to addresses at the time of death, since that was the only complete database available. This is a limitation of the study and could well lead to an information bias. However, it is assumed that there is the same probability of cases and controls changing addresses, moving away or towards transmission lines throughout adult life and this would more likely bring us to a non-differential classification error, as described by Copeland et al.[17]. Furthermore, as part of the case-control study described elsewhere[12], all addresses located up to 50 m of transmission lines were visited, and occupants were interviewed. The interview included questions of how much time the studied subject (case or control) lived at that address. Based on 89 interviews, the mean time of living in the same address was 22 years and 65% of the subjects had lived there for the past ten years prior to death. Although this sub-sample is not a random one of the general study population, results were similar to an evaluation of intra-urban mobility in the MRSP[18].

We attempted to control for confounding by adjusting the analyses for socioeconomic status, although we were limited by the available data. Analyses were adjusted for race, years of schooling, and marital status without material changes in results. Previous studies have also checked for confounding, usually adjusting for socioeconomic status, but yet no meaningful confounding factor has been identified.

One limitation of this study is that we could not retrieve any information on occupation, therefore risk analysis was not controlled for this.

While distance has the advantage of being relatively stable over the years and usually being less sensitive to changes (as it is exposure from other sources such as availability and usage of electrical appliances), proximity to transmission lines is a poor predictor of ELF-MF. Thus, for adults occupational exposure might be more important than residential one.

Several studies have looked at adult leukemia and various proxies of ELF-MF. Overall results are negative, but studies are inconsistent. Only two studies report results on adult leukemia and distance to transmission lines, which are consistent to our findings. A Swedish case-control study including 325 leukemia cases found an OR of 1.2 (95% CI=0.7-2.0) for subjects living up

to 50 m of transmission lines comparing to those living 100 m or further[19]. Similarly, a case-control study in Taiwan found an OR of 2.0 (95% CI=1.4-2.9) for cases living 50 m or closer of transmission lines comparing to those living 100 m or further[20].

To our knowledge, this is the largest case control study of adult leukemia and distance to power lines. Our findings are suggestive of a higher risk for leukemia among subjects living closer to transmission lines and for those with higher calculated fields at their homes, although risk was limited to lower voltage lines.

References

1. Wertheimer N, Leeper E. Electrical wiring configurations and childhood cancer. Am J Epidemiol. 1979;109(3):273-84.

2. WHO (World Health Organization). Extremely Low Frequency Fields. Environmental Health Criteria volume 238. Geneva, Switzerland: World Health Organization; 2007.

3. Swanson J, Kheifets L. Biophysical mechanisms and the weight of evidence for EMF. Radiat Res. 2006;165(4):470-8.

4. IARC (International Agency for Research on Cancer). Working Group on the Evaluation of Carcinogenic Risks to Humans. Non-ionizing radiation, Part 1: static and extremely low-frequency (ELF) electric and magnetic fields. IARC Monogr Eval Carcinog Risks Hum. 2002;80:1-395.

5. Ahlbom A, Day N, Feychting M, Roman E, Skinner J, Dockerty J, et al. A pooled analysis of magnetic fields and childhood leukemia. Br J Cancer. 2000;83(5):692-8.

6. Greenland S, Sheppard AR, Kaune WT, Poole C, Kelsh MA. A Pooled Analysis of Magnetic Field, Wire Codes and Chilhood Leukemia. Epidemiol. 2000;11(6):624-34.

7. Feychting M, Ahlbom A, Kheifets, L. EMF and Health. Annu Rev Public Health. 2005;26:165-89.

8. SCENIHR – Scientific Committee on Emerging and Newly Identified Health Risks. Health Effects of Exposure to EMF. Brussels, Belgium; 2009.

9. Kheifets L, Oksuzyan S. Exposure assessment and other challenges in non-ionizing radiation studies. Radiat Prot Dosimetry. 2008;132(2):139-47.

10. SEADE – Fundação Sistema Estadual de Análise de Dados. Demographic census [Portuguese]. [Online]. São Paulo, Brazil. 2000. [cited 2010 Jan 27]. Available http://www.seade.gov.br/produtos/msp/tabela_sintese.htm.

11. Paes NA. Assessment of completeness of death reporting in Brazilian states for the year. Rev Saude Pub. 2005;39(6):882-90.

12. Marcilio I. Evaluating mortality risk for leukemia, brain tumors and amyotrophic lateral sclerosis in relation to residential exposure to extremely low frequency magnetic fields: a case-control study in the city of São Paulo [PhD Dissertation]. [Portuguese]. São Paulo, Brazil: University of São Paulo; 2008.

13. Pereira Filho ML, Cardoso JR. Magnetic field exposure from multiple overhead transmission line in urban utilities corridor. In: Krawczyk A, Kubacki R, Wiak S, Antunes CL, eds. Proceedings of Electromagnetic Fields, Health and Environment'07, 10-12 September 2007, Wroclaw, Poland. Amsterdam, Netherlands: IOS Press; 2008. p. 47-52.

14. Linet MS, Devesa SS, Morgan GJ. The Leukemias. In: Schottenfeld D, Fraumeni JF, eds. Cancer Epidemiology and Prevention. New York, NY: Oxford University Press; 2006. p. 841-71.

15. Preston-Martin S, Munir R, Chakrabarti I. Nervous system. In: Schottenfeld D, Fraumeni JF, eds. Cancer Epidemiology and Prevention. New York, NY: Oxford University Press; 2006. p. 1173-95.

16. Yamamoto JF, Goodman MT. Patterns of leukemia incidence in the United States by subtype and demographic characteristics, 1997-2002. Cancer Causes Control. 2008;19(4):379-90.

17. Copeland KT, Checkoway H, McMichael AJ, Holbrook RH. Bias due to misclassification in the estimation of relative risk. Am J Epidemiol. 1977;105(5):488-95.

18. Barbon AL. Intra-urban residential mobility in big metropolises – Metropolitan Region of São Paulo, a case study [PhD Dissertation]. [Portuguese]. Campinas, Brazil: Pontifical Catholic University of Campinas; 2003.

19. Feychting M, Ahlbom A. Magnetic fields, leukemia, and central nervous system tumors in Swedish adults residing near high-voltage power lines. Epidemiol. 1994;5(5):501-9.

20. Li CY, Thériault G, Lin RS. Residential exposure to 60 Hz magnetic fields and adult cancer in Taiwan. Epidemiol. 1997;8(1):25-30.

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