Published in final edited form as:

Cancer Epidemiol. 2014 June ; 38(3): 307–313. doi:10.1016/j.canep.2014.02.010.

Potential Role of Selection Bias in the Association between Childhood Leukemia and Residential Magnetic Fields Exposure: A Population-based Assessment

Danna A. Slusky^a, Monique Does^a, Catherine Metayer^a, Gabor Mezei^b, Steve Selvin^a, and Patricia A. Buffler^{a,*}

^aSchool of Public Health, University of California, Berkeley, California

^bElectric Power Research Institute, Palo Alto, California

Abstract

Purpose—Data from the Northern California Childhood Leukemia Study (NCCLS) were used to assess whether selection bias may explain the association between residential magnetic fields (assessed by wire codes) and childhood leukemia as previously observed in case-control studies.

Methods—Wiring codes were calculated for participating cases, n=310; and non-participating cases, n=66; as well as for three control groups: first-choice participating, n=174; first-choice non-participating, n=252; and replacement (non-first choice participating controls), n=220.

Results—Participating controls tended to be of higher socioeconomic status than non-participating controls, and lower socioeconomic status was related to higher wire-codes. The odds ratio (OR) for developing childhood leukemia associated with high wire-codes was 1.18 (95% CI: 0.85,1.64) when all cases were compared to all first-choice controls (participating and non-participating). The OR for developing childhood leukemia in the high current category was 1.43 (95% CI: 0.91,2.26) when participating cases were compared to first-choice participating controls, but no associations were observed when participating cases were compared to non-participating controls (OR=1.06, 95% CI: 0.71,1.57) or to replacement controls (OR=1.06, 95% CI: 0.71,1.60).

Conclusions—The observed risk estimates vary by type of control group, and no statistically significant association between wire codes and childhood leukemia is observed in the California population participating in the NCCLS.

Keywords

Selection Bias; Leukemia; Magnetic Fields

© 2014 Elsevier Inc. All rights reserved.

Address correspondence to: Danna Slusky, Division of Epidemiology, UC Berkeley School of Public Health, 1995 University Ave, Ste 460, Berkeley, CA 94704. Fax +1 (510) 643-1735, dannaaharon@gmail.com.
* Author Deceased

Conflict of interest: None declared

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Introduction

The association between extremely low-frequency (ELF) magnetic fields (MF) and childhood leukemia has been extensively studied since the first publication of a case-control study by Wertheimer and Leeper (1979) [1], which used residential wire configuration codes (wire codes) as a surrogate for magnetic fields. Since this initial study, more than 30 epidemiological studies have been conducted, with improvements in assessment of magnetic fields by using calculated and directly measured fields. The results of the wire code studies have not been consistent, with several studies indicating a positive association between childhood leukemia and magnetic field exposures (assessed by wire codes) [1–4] while others showing no association [5, 6]. Most of these studies were included in two pooled analyses published in 2000 by Greenland et al. [7] and Ahlbom et al. [8], including original data from 15 and nine studies, respectively. Greenland et al. found no association between childhood leukemia and MF levels less than 0.3 μT , but reported a statistically significant 1.7 fold increased risk for MF levels over 0.3 μT (95% CI: 1.2, 2.3), compared to a reference value of less than 0.1 μT . The second pooled analysis, by Ahlbom et al., indicated a summary odds ratio of 2.0 (95% CI: 1.3, 3.1) for exposure $>0.4 \mu\text{T}$ as compared with exposure $<0.1 \mu\text{T}$ [8]. Following these two pooled analysis in 2002, the International Agency for Research on Cancer classified power-frequency magnetic fields as a possible human carcinogen (group 2B) [9].

In 2010, Kheifets et al. published the results of a subsequent pooled analysis using seven studies on residential magnetic fields and childhood leukemia that were published after 2000. The results were consistent with the previous pooled analyses with 1.4 fold increased risk for MF levels $>0.3 \mu\text{T}$ (95% CI: 0.9, 2.4) [10]. A recent California-based case-control study by Does et al. (2011) found no association of childhood leukemia with measured magnetic fields or household contact currents [11, 12], a hypothesized potential confounder of the magnetic field-leukemia association.

In spite of suggestive epidemiologic findings, there is no biological evidence from either cellular or animal studies to support the plausibility of the epidemiologic observations. Hence, it remains uncertain whether a causal association between childhood leukemia and MF exists. Among alternative explanations for the observed associations are the role of confounding factors, measurement errors, and selection bias.

Confounding effects of socioeconomic status (SES), residential mobility, residence type, social contacts, traffic density, and household contact currents have been raised as possible explanations for the observed associations [13–16]. However, despite extensive research, to date, no single confounder or set of confounders has been identified that could explain the observed association [14, 17].

Selection bias has been suggested as a potential explanation in several studies [18]. An adequate assessment of selection bias requires considerable additional resources as well as modifications in study design and has been difficult to conduct in most studies. To our knowledge, only three studies have attempted to assess the role of selection bias in the association between childhood leukemia and MF.

Gurney et al. (1995) assessed the relationship between family income and wire codes and noted that lower family income tended to be associated with the higher wire codes category [15]. Subsequently, Mezei et al. (2008) evaluated the role of control non-participation and the potential for selection bias in the 1999 Canadian case-control study of childhood leukemia and residential magnetic field exposure [6, 19]. These authors indicated that the first-choice non-participating controls tended to be of lower SES than the replacement controls, and that lower SES was related to higher wire code categories [19]. Consistent with the report by Hatch et al. (2000) regarding the impact of participation on risk estimates [14], Mezei et al. reported that the risk estimates for childhood leukemia in the highest exposure category were 1.6 (95% CI: 1.0, 2.6) when the actual participant controls (first-choice and non-first choice) were used, and 1.3 (95% CI: 0.8, 2.1) when all first-choice controls were used [19].

The aim of our study is to further assess whether selection bias may explain the observed epidemiologic association between magnetic fields and childhood leukemia as noted in previous studies by using residential information and wire code measurements for both participating and non-participating cases as well as controls. Because birth certificates were used in the control selection process, the NCCLS offers a rare opportunity to evaluate demographic characteristics and wire codes for a large number of non-participating and participating leukemia cases and controls.

Materials and Methods

Study population

The study population is a subset of the Northern California Childhood Leukemia Study, a case-control study of childhood leukemia in 35 northern and central California counties (1995–present) for whom residential wire codes could be determined. Cases with newly diagnosed leukemia are recruited from nine hospitals, usually within 72 hours of diagnosis.

The eligibility criteria for cases and controls of the parent study were: 1) residence in the study area; 2) age less than 15 years of age at the time of case diagnosis (reference date for controls); 3) no previous diagnosis of cancer; and 4) availability of at least one English or Spanish speaking parent or guardian. The wire code study conducted from 2002 to 2007 includes all NCCLS eligible subjects who were ascertained for the parent study from 1995 to 2006, regardless of their actual participation in the parent study. In addition, wire code study subjects were required to be born in the study area, have a valid residential California address (from birth certificate), and be less than 8 years of age at the time of case diagnosis (reference date for control). Cases and controls excluded from the NCCLS due to language were included in the wire code study if they met all other eligibility criteria (Figure 1).

A detailed description of control selection in the parent NCCLS was previously published [20–23]. Briefly, for each case, four potential controls were randomly selected from birth certificates from the California Office of Vital Records, matched on age, gender, Hispanic ethnicity, and maternal race [21]. One of the four birth certificate controls was randomly selected as the first potential control to be recruited for the study (referred to as ideal controls [A]). Professional interviewers contacted each family using standardized searching

protocols. If the first-choice control was found to be eligible and agreed to participate he/she was classified as a first-choice participating control [B]. If the first-choice control could not be located, was ineligible, or declined to participate he/she was classified as a first-choice non-participating controls [C], and the next randomly selected potential control was pursued. This procedure was repeated until an eligible and consenting non-first choice control was enrolled in the study, and these were classified as participating replacement controls [D]. If no control was enrolled by using the first set of four birth certificates, additional certificates were requested from the Center for Health Statistics and the process described above was repeated.

The process of case and control selection for the wire-code study is presented in Figure 1. For these analyses, ideal cases includes all participating (n=310) and non-participating (n=66) cases. The controls were divided into two groups. Ideal controls [A] consisted of all first-choice controls [B+C], n=426 (participating [B]; n=174, and non-participating [C]; n=252). The second group of actual controls [E], consisted of all participating controls [B +D], n=394 (first-choice participating controls [B]; n=174, and the participating replacement controls (non-first choice participating) [D]; n=220).

The study was approved by the University of California Committee for the Protection of Human Subjects, the California Health and Human Services Agency Committee for the Protection of Human Subjects, and the Institutional Review Boards of all the participant hospitals.

Data collection

Socio-demographic and residential address data were collected from birth certificates for all cases and controls, regardless of their participation status. Birth residences were assigned address-level latitude and longitude coordinates using a geographic information system (GIS). Each address was assigned to a 1990 or 2000 US Census block group, depending on the child's date of birth. The geocoding was carried out using ArcView GIS software [24]. Data from the U.S. Census Bureau were used to derive neighborhood measures of urbanization and SES. The methods for creating these variables have been previously described [25, 26]. In short, urbanization included three levels: large metro, city, and rural/town. To create the SES neighborhood variables, the California block groups were ranked separately by education, income, and occupation according to quartiles, based on the statewide adult population [27, 28].

For this study, the wire code method was used, despite its known limitations as a surrogate for magnetic fields, because this method can classify EMF exposure for residences of non-participants where there is no in-home access.

Engineering technicians trained in assessing wire codes recorded on a diagram the distance from the home of any overhead power lines within 150 feet of the residence, including transmission lines, thick and thin three-phase primary-distribution lines, any open (with separated wires) or spun (with wires bound together) secondary distribution lines, and first-span secondary distribution lines. The engineering technicians were blinded to case or control status. On the basis of the diagrams, a computer algorithm assigned a wire code to

each birth residence using the five category Wertheimer–Leeper classification defined as underground (UG), very low current configuration (VLCC), ordinary low current configuration (OLCC), ordinary high current configuration (OHCC), and very high current configuration (VHCC) [1].

Statistical Analysis

Descriptive analyses were conducted to compare the distribution of socio-demographic characteristics among several case and control groups as defined above (Methods). Correlations between categories of wire codes and socio-demographic characteristics were also calculated. Logistic regression analyses were performed using wiring codes as the predictor variable and case-control status as the outcome. The wire code categories used in the analyses include the five and three Wertheimer–Leeper categories.

Results

Demographic characteristics of the study population indicate that the participating controls tended to be of higher SES than the non-participating controls. Compared to non-participating controls, mothers of actual controls (first choice and replacement) had a significantly higher level of education, were older at the child's birth, and were more likely to live in a single-family home or in a neighborhood with a higher SES (Table 1). In addition, wire codes were strongly associated with socio-demographic and residential characteristics, with lower SES related to higher wire codes (Table 2).

Using the three categories Wertheimer-Leeper (WL) classification with the combined category of UG and VLCC as the referent, ORs were calculated for the ideal cases compared to the ideal controls and for the actual cases compared to the actual controls (Table 3). These analyses indicated a weak and non-statistically significant association between childhood leukemia and high wire codes (OHCC and VHCC combined) for both comparisons. In addition, when the neighborhood SES variables were included in the logistic regression models, the risk estimates did not change (data not shown).

The comparison of actual (participating) cases with the different control groups, i.e., 1st choice participating [B], 1st choice non-participating [C] and replacement [D], allows an assessment of potential selection bias (Table 4). Using the three category WL classification and the lowest wire codes (UG+VLCC) as the referent category, the observed risk estimates for all three control groups were not consistent. In addition, when the five categories of the Wertheimer-Leeper wire configuration codes were used, with UG (underground) as the referent, slightly different results were observed. All 16 cases assigned to the very high wire code category (VHCC) showed a markedly lower risk of childhood leukemia, when compared to the first-choice participating controls [B], first-choice non-participating controls [C], and replacement controls [D] (Table 4). These results were inconsistent with no clear gradient of risk by wire code category and it could be that these results were obtained simply by the low number of cases in the VHCC category.

In summary, the odds ratio (OR) for developing childhood leukemia associated with OHCC/VHCC was 1.18 (95% CI: 0.85, 1.64) for the ideal comparison of all cases compared to all

first-choice controls [A]. The ORs for developing childhood leukemia in the OHCC/VHCC category was 1.43 (95% CI: 0.91, 2.26) when participating cases were compared to first-choice participating controls [B], and 1.06 (0.71, 1.57) when compared to non-participating controls [C] and 1.06 (0.71, 1.60) when compared to replacement controls [D] (Tables 3, 4, 5).

Discussion

This is the first study to publish its results for both participating and non-participating cases and controls in a study of magnetic fields (assessed by wire codes) and childhood leukemia. Because the calculation of residential wire codes does not require case or control consent to participate, we had a rare opportunity to evaluate the association of childhood leukemia and MF without the influence of selection bias for both cases and controls. While residential MF exposures were assessed indirectly using wire codes, it is important to note that this method was used in the original study by Wertheimer and Leeper (1979) that initially suggested a possible association of magnetic fields and childhood leukemia, and thus set in motion over three decades of research on this possible association.

In this study, the most robust analyses using ideal case and ideal control groups indicate a lack of an association between childhood leukemia and MF (assessed by wire codes). Our results suggest that in an ideal situation when no participation bias exists, it is most likely that there is no association between childhood leukemia and magnetic fields. In addition, the risk estimate for the actual cases and controls were very similar (OR=1.21; 95% CI 0.85–1.72) to that for the ideal cases and controls indicating that when replacement controls (non-first choice controls) were used, the results did not change. Despite observed differences in SES, the wire codes results of the actual controls and the ideal controls were very similar in the NCCLS study population.

The results also indicate that in the NCCLS, the observed OR for the association between childhood leukemia and magnetic field exposures (as estimated from wire codes) is not likely to be strongly affected by bias due to differential participation. The potential for selection bias appears to have been attenuated by the NCCLS control recruitment process which uses the statewide birth registry to provide a comparable and representative replacement participant for each control, and aggressively strives to achieve high participation rates throughout the study. For participants in the wire code analyses, the overall participation rates among eligible cases and controls were 80% and 70%, respectively.

In addition, although it may be that the randomly selected stratified replacement controls [D] have a slightly higher SES than the non-participating “first-choice” controls [C], our results indicate that the participating cases are also of slightly higher SES than the non-participating cases (data not shown). Due to the similar participation probabilities among cases and controls, the overall odds ratios is less likely to be biased.

The lack of an association between childhood leukemia and magnetic field exposures (assessed by wire codes) observed in our study is consistent with the conclusions of some

previous studies [5, 6] but not others [1–4]. Most of the previous studies indicating a positive association have raised the possibility that the observed association could be the result of uncontrolled confounding factors or selection bias. In our study, adjustment for potentially confounding factors, including Hispanic status, neighborhood and individual socioeconomic variables, did not influence the observed risk estimates.

As wire codes are associated both with participation status and SES, it is possible that the associations between childhood leukemia and estimated magnetic field exposure (based on wire-codes) as reported in previous studies were biased. Indeed, our results indicate that the value of the OR for the observed association depends on the completeness of the control group. In our study, participating cases had non-significant increased odds of being in the high wire-code category (OHCC/VHCC) when compared to the first-choice participating controls [B] (OR=1.43, 95% CI: 0.91, 2.26). However, no such increased risk was observed when comparing the cases to the first-choice non-participating controls [C] (OR=1.06, 95% CI: 0.71, 1.57) or to the replacement controls [D] (OR=1.06, 95% CI: 0.71, 1.60). These findings indicate that the association between childhood leukemia and wire codes is influenced by the characteristics of the control group and therefore prone to selection bias.

One strength of this study is the availability of demographic and wire code measurements for a large group of non-participating cases as well as controls, and the resulting ability to assess the effect of selection bias in a case-control study of childhood leukemia.

A limitation of our study is the use of the residence at time of birth, as it is the only available residence information for the non-participating cases and controls. To reduce a potential effect of misclassification, an additional eligibility criterion was added to our study: being less than 8 years of age at the time of case diagnosis (referent date for controls). This criterion accounted for the majority of the cases and controls that were excluded from the wire code study. The following cases and controls were excluded due to age > 8: participant cases n=110; non-participant cases n=41; first-choice participating controls (B) n= 57; first-choice non-participating controls (C) n=71; and replacement controls (D) n=73. In addition, since the geographical area of wire code measurements needed to be defined, all cases and controls needed to be born in the study area. As noted in the method section, while all of the controls and the non-participating cases were born in California, several participating cases (n=31) were born outside of California and therefore, were excluded from the wire code study. Although representing a small percentage, it is unknown whether this exclusion has introduced a bias.

Another limitation is the use of wire codes as a surrogate for magnetic fields exposure since this surrogate is known to have limited ability to estimate magnetic field exposure and was used only in North American studies [29]. However, we used wire codes because our aim was to assess the role of selection bias and this approach could be applied to any known address without requiring active participation or property access.

Our results indicate a lack of an association between wire codes and childhood leukemia, and that in our analysis selection bias is not likely to be an important factor. However, we noted that risk estimates can vary depending on the characteristics of the control group.

Therefore, it could be that the elevated risk estimates observed in earlier studies may have been influenced by bias due to less representative selection of control subjects, especially those using the random-digit dialing method for control selection [2, 4].

Because supportive laboratory evidence of an association of magnetic fields with risk of childhood leukemia is lacking and the biophysical plausibility of the carcinogenicity of MFs is questionable, the epidemiologic literature supporting a positive association deserves careful scrutiny. It is essentially on the basis of earlier epidemiologic evidence, in itself, that questions regarding the long-term human health effects of EMF have relied and this evidence does not appear to provide a strong foundation for a causal interpretation.

Acknowledgments

Source of Funding: This work was supported by the National Institute of Environmental Health Sciences at the National Institute of Health [PS42 ES04705 and R01 ES09137] and the Electric Power Research Institute [EP-P12994/C6483].

The authors would like to thank all the participating hospitals and clinical collaborators of the Northern California Childhood Leukemia Study, as well as Susan Burns of the University of California Survey Research Center and Chris Hooper of Enertech Consultants. We would also like to acknowledge all of the study participants and their families and the dedicated staff and investigators of the Northern California Childhood Leukemia Study.

References

1. Wertheimer N, Leeper E. Electrical wiring configurations and childhood cancer. *Am J Epidemiol.* 1979; 109:273–84. [PubMed: 453167]
2. Savitz DA, Wachtel H, Barnes FA, John EM, Tvrdik JG. Case-control study of childhood cancer and exposure to 60-Hz magnetic fields. *Am J Epidemiol.* 1988; 128:21–38. [PubMed: 3164167]
3. Schuz J, Grigat JP, Brinkmann K, Michaelis J. Residential magnetic fields as a risk factor for childhood acute leukaemia: results from a German population-based case-control study. *Int J Cancer.* 2001; 91:728–35. [PubMed: 11267988]
4. London SJ, Thomas DC, Bowman JD, Sobel E, Cheng TC, Peters JM. Exposure to residential electric and magnetic fields and risk of childhood leukemia. *Am J Epidemiol.* 1991; 134:923–37. [PubMed: 1843457]
5. Linet MS, Hatch EE, Kleinerman RA, Robison LL, Kaune WT, Friedman DR, et al. Residential exposure to magnetic fields and acute lymphoblastic leukemia in children. *N Engl J Med.* 1997; 337:1–7. [PubMed: 9203424]
6. McBride ML, Gallagher RP, Theriault G, Armstrong BG, Tamaro S, Spinelli JJ, et al. Power-frequency electric and magnetic fields and risk of childhood leukemia in Canada. *Am J Epidemiol.* 1999; 149:831–42. [PubMed: 10221320]
7. Greenland S, Sheppard AR, Kaune WT, Poole C, Kelsh MA. Childhood Leukemia-EMF Study Group. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. *Epidemiology.* 2000; 11:624–34. [PubMed: 11055621]
8. Ahlbom A, Day N, Feychting M, Roman E, Skinner J, Dockerty J, et al. A pooled analysis of magnetic fields and childhood leukaemia. *Br J Cancer.* 2000; 83:692–8. [PubMed: 10944614]
9. IARC 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. [PubMed: 12071196]
10. Kheifets L, Ahlbom A, Crespi CM, Draper G, Hagihara J, Lowenthal RM, et al. Pooled analysis of recent studies on magnetic fields and childhood leukaemia. *Br J Cancer.* 2010; 103:1128–35. [PubMed: 20877339]
11. Does M, Scelo G, Metayer C, Selvin S, Kavet R, Buffler P. Exposure to electrical contact currents and the risk of childhood leukemia. *Radiat Res.* 2011; 175:390–6. [PubMed: 21388283]

12. Kavet R, Hooper C, Buffler P, Does M. The Relationship between Residential Magnetic Fields and Contact Voltage: A Pooled Analysis. *Radiat Res.* 2011
13. Jones TL, Shih CH, Thurston DH, Ware BJ, Cole P. Selection bias from differential residential mobility as an explanation for associations of wire codes with childhood cancer. *J Clin Epidemiol.* 1993; 46:545–8. [PubMed: 8501481]
14. Hatch EE, Kleinerman RA, Linet MS, Tarone RE, Kaune WT, Auvinen A, et al. Do confounding or selection factors of residential wiring codes and magnetic fields distort findings of electromagnetic fields studies? *Epidemiology.* 2000; 11:189–98. [PubMed: 11021619]
15. Gurney JG, Davis S, Schwartz SM, Mueller BA, Kaune WT, Stevens RG. Childhood cancer occurrence in relation to power line configurations: a study of potential selection bias in case-control studies. *Epidemiology.* 1995; 6:31–5. [PubMed: 7888441]
16. Feychting M, Svensson D, Ahlbom A. Exposure to motor vehicle exhaust and childhood cancer. *Scand J Work Environ Health.* 1998; 24:8–11. [PubMed: 9562395]
17. Kheifets L, Mezei G, Greenland S. Comment concerning “Childhood leukemia and residential magnetic fields: are pooled analyses more valid than the original studies?” (*Bioelectromagnetics* 27:1–7 [2006]). *Bioelectromagnetics.* 2006; 27:674–5. discussion 5–6. [PubMed: 16917870]
18. Mezei G, Kheifets L. Selection bias and its implications for case-control studies: a case study of magnetic field exposure and childhood leukaemia. *Int J Epidemiol.* 2006; 35:397–406. [PubMed: 16303812]
19. Mezei G, Spinelli JJ, Wong P, Borugian M, McBride ML. Assessment of selection bias in the Canadian case-control study of residential magnetic field exposure and childhood leukemia. *Am J Epidemiol.* 2008; 167:1504–10. [PubMed: 18483123]
20. Chang JS, Metayer C, Fear NT, Reinier K, Yin X, Urayama K, et al. Parental social contact in the work place and the risk of childhood acute lymphoblastic leukaemia. *Br J Cancer.* 2007; 97:1315–21. [PubMed: 17923868]
21. Ma X, Buffler PA, Layefsky M, Does MB, Reynolds P. Control selection strategies in case-control studies of childhood diseases. *Am J Epidemiol.* 2004; 159:915–21. [PubMed: 15128601]
22. Bartley K, Metayer C, Selvin S, Ducore J, Buffler P. Diagnostic X-rays and risk of childhood leukaemia. *Int J Epidemiol.* 2010; 39:1628–37. [PubMed: 20889538]
23. Slusky DA, Metayer C, Aldrich MC, Ward MH, Lea CS, Selvin S, et al. Reliability of maternal-reports regarding the use of household pesticides: Experience from a case-control study of childhood leukemia. *Cancer Epidemiol.* 2012; 36:375–80. [PubMed: 22277328]
24. Environmental Systems Research Institute I. ArcView, version 3.3. Redlands (CA): ESRI; 2000.
25. Reynolds P, Hurley SE, Gunier RB, Yerabati S, Quach T, Hertz A. Residential proximity to agricultural pesticide use and incidence of breast cancer in California, 1988–1997. *Environ Health Perspect.* 2005; 113:993–1000. [PubMed: 16079069]
26. Reynolds P, Hurley SE, Quach AT, Rosen H, Von Behren J, Hertz A, et al. Regional variations in breast cancer incidence among California women, 1988–1997. *Cancer Causes Control.* 2005; 16:139–50. [PubMed: 15868455]
27. United States Bureau of the Census. Tiger2000 [data file]. Washington DC: US Census Bureau; 2002.
28. United States Bureau of the Census. Modified age/race, sex and Hispanic origin (MARS) state and county file [data file]. Washington DC: US Bureau of the Census; 1992. Census of population and housing.
29. Tworoger SS, Davis S, Schwartz SM, Mirick DK. Stability of Wertheimer-Leeper wire codes as a measure of exposure to residential magnetic fields over a 9- to 11-year interval. *J Expo Anal Environ Epidemiol.* 2002; 12:448–54. [PubMed: 12415494]

Figure 1.

Selection of Cases and Controls for Wire Code Study, NCCLS, 2002–2007.

WC = wire codes

^a Not eligible for the following reasons: previous treatment or diagnosis for cancer, residence outside of the study area, no guardian who speaks English or Spanish.

^b Eligible for WC only: no guardian who speaks English or Spanish.

^c Not eligible for WC study for the following reasons: age > 8, born outside of study area, residence not possible to wire code for technical reasons or missing address.

Table 1
 Characteristics of Cases and Controls in the Wire Code Study, NCCLS, 2002–2007

	Participant cases n=310		1 st choice participant controls [B] n=174		1 st choice non-participant controls [C] n=252		Replacement controls [D] n=220		[B] vs. [C]		[C] vs. [D]	
	No. (%)		No. (%)	<i>P^a</i>	No. (%)	<i>P^a</i>	No. (%)	<i>P^a</i>	<i>P^b</i>		<i>P^c</i>	
Gender												
Male	169 (54.5)		93 (53.4)	0.821	136 (54.0)	0.897	118 (53.6)	0.841	0.916		0.943	
Female	141 (45.5)		81 (46.6)		116 (46.0)		102 (46.4)					
Age at diagnosis, years												
Mean (SE)	3.7 (0.1)		3.3 (0.1)	0.469	3.7 (0.1)	0.118	3.9 (0.1)	0.330	0.040		0.589	
Race												
Non-Hispanic White	131 (42.2)		86 (49.4)	0.405	79 (31.4)	0.067	87 (39.6)	0.861	0.002		0.248	
Hispanic	127 (41.0)		66 (37.9)		121 (48.0)		94 (42.7)					
Non-Hispanic Black	12 (3.9)		6 (3.5)		13 (5.1)		7 (3.2)					
Other	40 (12.9)		16 (9.2)		39 (15.5)		32 (14.5)					
Maternal age at child's birth, years												
Mean (SE)	28.2 (0.4)		29.3 (0.5)	0.070	26.2 (0.4)	0.026	28.7 (0.4)	0.308	< 0.001		< 0.003	
Maternal education, years												
Mean (SE)	12.2 (0.2)		12.9 (0.3)	0.023	11.1 (0.2)	0.001	13.4 (0.2)	0.016	< 0.001		< 0.001	
Birth residence type												
Single family homes	207 (66.7)		135 (77.6)	0.098	147 (58.3)	0.181	152 (69.1)	0.926	< 0.001		0.093	
Apartment	62 (20.0)		24 (13.8)		64 (25.4)		39 (17.7)					
Multiple family home	33 (10.7)		12 (6.9)		30 (11.9)		23 (10.5)					
Trailer & other	8 (2.6)		3 (1.7)		11 (4.4)		6 (2.7)					
Neighborhood type												
Single family homes	210 (67.7)		134 (77.0)	0.187	146 (57.9)	0.085	150 (68.2)	0.505	< 0.001		0.015	
Apartment	42 (13.6)		18 (10.3)		43 (17.0)		32 (14.6)					
Multiple family home	36 (11.6)		13 (7.5)		34 (13.5)		29 (13.2)					
Trailer & other	22 (7.1)		9 (5.2)		29 (11.5)		9 (4.0)					
Neighborhood SES												
Low	62 (20.1)		31 (17.9)	0.605	89 (35.3)	< 0.001	33 (15.0)	0.401	< 0.001		< 0.001	

	Participant cases n=310	1 st choice participant controls [B] n=174		1 st choice non- participant controls [C] n=252		Replacement controls [D] n=220		[B] vs. [C]		[C] vs. [D]	
		No. (%)	<i>P^a</i>	No. (%)	<i>P^a</i>	No. (%)	<i>P^a</i>	<i>P^b</i>		<i>P^c</i>	
Med low	80 (25.9)	39 (22.5)		64 (25.4)		58 (26.4)					
Med high	85 (27.5)	48 (27.8)		45 (17.9)		27 (27.3)					
High	82 (26.5)	55 (31.8)		54 (21.4)		69 (31.4)					
Urbanization level											
Large metro	167 (53.9)	91 (52.6)	0.037	141 (56.0)	0.760	137 (62.3)	0.154	0.117		0.361	
City	81 (26.1)	32 (18.5)		59 (23.4)		46 (20.9)					
Rural/town	62 (20.0)	50 (28.9)		52 (20.6)		37 (16.8)					

^a *P* comparing controls to cases derived from chi-square and Student's *t* tests

^b *P* comparing 1st choice participant controls [B] to 1st choice non-participant controls [C]

^c *P* comparing Replacement controls [D] to 1st choice non-participant controls [C]

Table 2
Socio-demographic and Residential Characteristics for 1022 Homes by Wire Code Category, NCCLS, 2002–2007

	Underground No. (%)	VLCC No. (%)	OLCC No. (%)	OHCC & VHCC No. (%)	<i>p</i> ^a
Race					
Non-Hispanic White	175 (43.4)	47 (50.5)	82 (36.3)	93 (31.0)	< 0.001
Hispanic	148 (36.7)	32 (34.4)	112 (49.6)	149 (49.7)	
Non-Hispanic Black	10 (2.5)	3 (3.2)	10 (4.4)	18 (6.0)	
Other	70 (17.4)	11 (11.8)	22 (9.7)	40 (13.3)	
Maternal age at child's birth, years					
< 20	113 (28.0)	29 (31.2)	79 (35.0)	102 (34.0)	0.311
20–24	125 (31.0)	24 (23.6)	55 (24.3)	80 (26.7)	
25–29	115 (28.5)	28 (30.1)	54 (23.9)	73 (24.3)	
30–34	50 (12.4)	14 (15.1)	38 (16.8)	45 (15.0)	
Maternal education, years					
12	182 (46.0)	49 (52.7)	139 (62.1)	172 (58.3)	0.004
13–15	92 (23.2)	21 (22.6)	35 (15.6)	56 (19.0)	
16	122 (30.8)	23 (24.7)	50 (22.3)	67 (22.7)	
Residence type					
Single family homes	263 (65.3)	58 (62.4)	161 (71.2)	199 (66.3)	0.163
Apartment	93 (23.1)	23 (24.7)	38 (16.8)	54 (18.0)	
Multiple family homes	34 (8.4)	7 (7.5)	23 (10.2)	39 (13.0)	
Trailer & other	13 (3.2)	5 (5.4)	4 (1.8)	8 (2.7)	
Neighborhood type					
Single family homes	264 (65.5)	55 (59.1)	163 (72.1)	200 (66.7)	< 0.001
Apartment	77 (19.1)	21 (22.6)	22 (9.8)	26 (8.6)	
Multiple family homes	37 (9.2)	9 (9.7)	24 (10.6)	44 (14.7)	
Trailer & other	25 (6.2)	8 (8.6)	17 (7.5)	30 (10.0)	
Neighborhood SES					
Low	58 (14.4)	22 (23.9)	80 (35.6)	77 (25.7)	< 0.001
Med low	94 (23.4)	23 (25.0)	52 (23.1)	87 (29.0)	
Med high	114 (28.4)	22 (23.9)	50 (22.2)	66 (22.0)	

	Underground No. (%)	VLCC No. (%)	OLCC No. (%)	OHCC & VHCC No. (%)	<i>P</i> ^a
High	136 (33.8)	25 (27.2)	43 (19.1)	70 (23.3)	
Urbanization level					
Large metro	189 (63.0)	128 (56.6)	49 (53.3)	204 (50.8)	0.015
City	57 (19.0)	49 (21.7)	18 (19.6)	115 (28.6)	
Rural/town	54 (18.0)	49 (21.7)	25 (27.1)	83 (20.6)	

VLCC = very low current code; OLCC = ordinary low current code; OHCC = ordinary high current code; VHCC = very high current code

^a *P* derived from chi-square tests for categorical variables and from Student's *t*-test for continuous variables

Table 3

Odds Ratio (95% Confidence Intervals) for Childhood Leukemia and Wire Code Categories comparing Ideal Cases vs. Ideal Controls and Actual Cases vs. Actual Controls, NCCLS, 2002–2007

Ideal cases n=376		Ideal controls [B+C] n=426		Actual cases n=310		Actual controls [B+D] n=394	
No. (%)	No. (%)	OR (95%CI) vs. Ideal cases ^a	No. (%)	No. (%)	OR (95%CI) vs. Actual cases ^a	No. (%)	OR (95%CI) vs. Actual cases ^a
Wertheimer-Leeper wire code with three categories							
UG/VLCC	175 (46.6)	216 (50.7)	Ref.	145 (46.8)	200 (50.8)	Ref.	
OLCC	87 (23.1)	89 (20.9)	1.25 (0.87, 1.79)	72 (23.2)	88 (22.3)	1.14 (0.77, 1.67)	
OHCC/VHCC	114 (30.3)	121 (28.4)	1.18 (0.85, 1.64)	93 (30.0)	106 (26.9)	1.21 (0.85, 1.72)	
Wertheimer-Leeper wire code with five categories							
UG	142 (37.7)	173 (40.6)	Ref.	116 (47.4)	162 (41.1)	Ref.	
VLCC	33 (8.8)	43 (10.1)	0.96 (0.58, 1.60)	29 (9.4)	38 (9.7)	1.08 (0.63, 1.85)	
OLCC	87 (23.1)	89 (20.9)	1.24 (0.85, 1.81)	72 (23.2)	88 (22.3)	1.16 (0.78, 1.73)	
OHCC	93 (24.7)	81 (19.0)	1.45 (0.99, 2.11)	77 (24.8)	72 (18.3)	1.50 (1.00, 2.24)	
VHCC	21 (5.6)	40 (9.4)	0.64 (0.36, 1.13)	16 (5.2)	34 (8.6)	0.65 (0.34, 1.23)	

VLCC = very low current code; OLCC = ordinary low current code; OHCC = ordinary high current code; VHCC = very high current code

^aOdds Ratios and 95% confidence intervals comparing controls to cases estimated using multiple logistic regressions adjusting for: child's age at diagnosis (reference date for controls), sex, Hispanic status, and maternal race

Table 4

Odds Ratio (95% Confidence Intervals) for Childhood Leukemia and Wire Code Categories by Control Group Used, NCCLS, 2002–2007

Participant Cases [1] n=310		1 st choice participant controls[B] vs. [1] n=174		1 st choice non participant controls [C] vs.[1] n=252		Replacement controls [D] vs. [1] n=220	
	no. (%)	no. (%)	OR (95%CI) ^d	no. (%)	OR (95%CI) ^d	no. (%)	OR (95%CI) ^d
Wertheimer-Leeper wire code with three categories							
UG/VLCC	145 (46.8)	95 (54.6)	Ref.	121 (48.0)	Ref.	105 (47.7)	Ref.
OLCC	72 (23.2)	38 (21.8)	1.22 (0.76, 1.97)	51 (20.2)	1.28 (0.82, 1.99)	50 (22.7)	1.07 (0.69, 1.68)
OHCC/VHCC	93 (30.0)	41 (23.6)	1.43 (0.91, 2.26)	80 (31.8)	1.06 (0.71, 1.57)	65 (29.6)	1.06 (0.71, 1.60)
Wertheimer-Leeper wire code with five categories							
UG	116 (47.4)	74 (42.5)	Ref.	99 (39.3)	Ref.	88 (40.0)	Ref.
VLCC	29 (9.4)	21 (12.1)	0.88 (0.47, 1.67)	22 (8.7)	1.16 (0.62, 2.18)	17 (7.7)	1.33 (0.69, 2.58)
OLCC	72 (23.2)	38 (21.8)	1.19 (0.73, 1.96)	51 (20.2)	1.32 (0.83, 2.10)	50 (22.7)	1.15 (0.72, 1.83)
OHCC	77 (24.8)	28 (16.1)	1.70 (1.00, 2.88)	53 (21.0)	1.38 (0.88, 2.18)	44 (20.0)	1.38 (0.86, 2.20)
VHCC	16 (5.2)	13 (7.5)	0.74 (0.33, 1.65)	27 (10.7)	0.54 (0.27, 1.07)	21 (9.6)	0.59 (0.29, 1.20)

VLCC = very low current code; OLCC = ordinary low current code; OHCC = ordinary high current code; VHCC = very high current code

^aOdds Ratios and 95% confidence intervals comparing controls to cases estimated using multiple logistic regressions adjusting for: child's age at diagnosis (reference date for controls), sex, Hispanic status, and maternal race

Table 5

Summary of Odds Ratio (95% Confidence Intervals) for Childhood Leukemia and High Wire Code Categories (OHCC + VHCC) with Low Wire Code Categories UG + VLCC) as Referent by Type of Control Group, NCCLS, 2002–2007

Control Group	Wertheimer-Leeper OR (95%CI) ^a vs. participant cases OHCC + VHCC
[A] Ideal (all first-choice) controls (B & C) ^b	1.18 (0.85, 1.64)
[B] First-choice participating	1.43 (0.91, 2.26)
[C] First-choice non-participating	1.06 (0.71, 1.57)
[D] Replacement controls (non-first choice participating controls)	1.06 (0.71, 1.60)
[E] Actual controls (B & D)	1.21 (0.85, 1.72)

^a Odds Ratios and 95% confidence intervals comparing controls to participating cases estimated using multiple logistic regressions adjusting for: Child's age at diagnosis (reference date for controls), sex, Hispanic status, and maternal race

^b Odds Ratios and 95% confidence intervals comparing Ideal controls to Ideal cases