American Journal of Epidemiology

Vol. 151, No. 5
Printed in U.S.A.

# Are Children Living Near High-Voltage Power Lines at Increased Risk of Acute Lymphoblastic Leukemia?

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In the National Cancer Institute/Children's Cancer Group case-control study of childhood acute lymphoblastic leukemia (1989–1993), living in a home with a high-voltage wire code was not associated with disease risk. To further investigate risk near power lines, the authors analyzed distance to transmission and three-phase primary distribution lines within 40 m of homes and created an exposure index of distance and strength of multiple power lines (408 case-control pairs). Neither distance nor exposure index was related to risk of childhood acute lymphoblastic leukemia, although both were associated with in-home magnetic field measurements. Residence near high-voltage lines did not increase risk. *Am J Epidemiol* 2000;151:512–15.

child; electric wiring; electromagnetic fields; environmental exposure; leukemia, lymphocytic, acute

A case-control study of childhood acute lymphoblastic leukemia and magnetic fields was recently conducted by the National Cancer Institute and the Children's Cancer Group (1). The study failed to find an association between residential wire code level and risk of this neoplasm, unlike previous US studies (2, 3). It has been suggested that the Wertheimer-Leeper wire code scheme (4) was not valid for use in the study's nine-state area (5) and that, regardless of the published findings, leukemia risk might be increased among children living near high-voltage power lines (6). The Wertheimer-Leeper wire code classification is a univariate summary of distance and wiring configuration (4, 7), and is intended to represent magnetic field exposure from power lines. The strengths of magnetic fields decrease with increasing distance from power lines (8). We investigated various components of wire code separately and together to see whether we could identify a measure that was more predictive of risk of childhood acute lymphoblastic leukemia.

Received for publication February 2, 1999, and accepted for publication May 12, 1999.

Abbreviations: OHCC, ordinary high current configuration; OLCC, ordinary low current configuration; VHCC, very high current configuration; VLCC, very low current configuration.

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## MATERIALS AND METHODS

### Study subjects

Subjects were a subset of cases and controls enrolled in a nationwide study of childhood acute lymphoblastic leukemia conducted by the Children's Cancer Group (9). Cases were children aged <15 years with acute lymphoblastic leukemia diagnosed between 1989 and 1993 at participating Children's Cancer Group hospitals. Controls were selected by random digit dialing and were matched to cases on age (±25 percent), race, and geographic area. The Children's Cancer Group had identified 942 cases and 1,292 controls residing in nine midwestern and mid-Atlantic states, and 851 cases (90 percent) and 825 controls (64 percent) were eligible for the measurement study. Based on the residential history of 832 cases (98 percent) and 801 controls (97 percent), 428 cases and 428 controls who had been living in one home for at least 70 percent of the reference period (5 years preceding diagnosis) were eligible for wire coding. We excluded eight case-control pairs because of Down's syndrome and 12 pairs because the technician could not locate the home or accurately diagram the power lines. This left 408 pairs eligible for analysis (1).

### Wire code measurements

Two trained technicians, blinded as to case-control status, recorded the distances between subjects' residences and all overhead transmission, three-phase primary distribution (thick or thin), first span secondary distribution, and endpole lines passing within 40 m (130 feet) of the subject's residence. Independent rediagramming of 187 homes revealed a high level of agreement between the two technicians (10).

An algorithm assigned one of four wire codes to each residence based on distance and wiring structure, as defined by the Wertheimer-Leeper wire coding classification (4): very high current configuration (VHCC), ordinary high current configuration (OHCC), ordinary low current configuration (OLCC), and very low current configuration (VLCC). If no overhead power lines of any type were visible within 46 m (150 feet), houses were classified as having only underground power lines.

### Distance

In two earlier US studies (2, 3), increased risk of childhood leukemia was reported for children living in homes with the VHCC classification, and a home can be classified as VHCC only through proximity to transmission or three-phase primary distribution lines. Consequently, we used distances to all transmission and thick and thin three-phase primary distribution lines passing within 40 m (130 feet) of a house. When more than one line was present, we used the distance from the subject's residence to the closest power line.

### Exposure index

An exposure index was created to take into account distance and relative load for all transmission and three-phase primary distribution lines that passed within 40 m of a residence. First, an index, $I_k$, for each power line was calculated using the formula

$$I_k = \xi_k/(x_k^2 + h_k^2),$$

where $\xi_k$ is a weighting factor for the $k$th power line that accounts for differences between transmission and primary distribution lines, $x_k$ is the horizontal distance measured perpendicular from the $k$th power line to a point located 1.8 m (6 feet) inside the nearest wall of the home, and $h_k$ is the height of the $k$th power line. The form of this index is dictated by physical theory (11). Based on our experience and best judgment, the weighting factors, $\xi_k$, used in this formula were chosen to equal 10,000 for transmission lines, 5,000 for thick three-phase primary lines, and 3,500 for thin three-phase primary lines. The horizontal distances, $x_k$, were directly measured by our wire mappers. Finally, since power-line heights were not measured, we selected $h_k$ = 9.1 m (30 feet) as an estimate of the average height of power lines located near residences.

Next, the indices for all power lines were combined into an overall exposure index, $I$, using the formula

$$I = \sqrt{I_1^2 + I_2^2 + \ldots + I_N^2}.$$

This formula was developed on the basis of engineering considerations (12) and reflects the fact that the directions and electrical phases of the magnetic fields produced by multiple power lines will not, in general, equal each other.

### Statistical analysis

Matched-pairs analyses were used to evaluate childhood leukemia risk, and we used conditional logistic regression to control for gender, mother's educational level, and annual family income. We evaluated distance as a categorical variable and the exposure index as categorical and continuous variables to examine the effect of power lines on risk. Categorical variables of exposure were defined by the quartile distribution among controls. We examined the mean 24-hour child's bedroom magnetic field measurement for homes within each distance category.

## RESULTS

Most subjects ($n$ = 601) lived more than 40 m from a transmission or three-phase primary distribution line; 181 had homes with one line within 40 m; 29 had homes with two lines within 40 m, and five subjects had homes with three or more lines within 40 m. Very few participants (10 cases and 20 controls) lived within 40 m of a transmission line, whereas 105 cases and 98 controls lived within 40 m of at least one three-phase primary distribution line.

All 30 homes within 40 m of a transmission line were coded either OHCC ($n$ = 9) or VHCC ($n$ = 21) (table 1). Residences with three-phase primary distribution lines within 40 m were distributed across three categories: OLCC ($n$ = 29), OHCC ($n$ = 124) and VHCC ($n$ = 50). Distances from the closest transmission line to the subject's residence ranged from 4.6 m to 40 m, and from 1.8 m to 40 m for the closest three-phase primary distribution lines.

The mean magnetic field level of homes within each distance category increased with decreasing distance, ranging from 0.09 μT for residences greater than 40 m from a power line to 0.21 μT for residences with the nearest lines at 0–14 m (table 2). However, the risk of childhood acute lymphoblastic leukemia decreased nonsignificantly with decreasing distance from either the closest power line or the closest three-phase primary distribution line to the main residence

**TABLE 1.** Distribution of wire code categories by distance from the main residence to the nearest overhead power line in a nine-state US study of childhood acute lymphoblastic leukemia, 1989–1993

| Distance (m) to nearest power line | Wertheimer-Leeper wire code category | | | | |
|---|---|---|---|---|---|
| | Underground/ very low current configuration | Ordinary low current configuration | Ordinary high current configuration | Very high current configuration | Total |
| 0–14 | 0 | 0 | 15 | 49 | 64 |
| 15–23 | 0 | 6 | 64 | 1 | 71 |
| 24–40 | 0 | 23 | 57 | 0 | 80 |
| >40 | 352 | 207 | 42 | 0 | 601 |
| Total | 352 | 236 | 178 | 50 | 816 |

(table 2). The risks for living within 40 m of a transmission line were all below 1.

Using the exposure index that takes all nearby power lines into account, the risk of childhood leukemia was not related to exposure level (table 3). Mean residential magnetic field levels rose with increasing exposure index level: 0.09 μT, 0.09 μT, 0.14 μT, and 0.21 μT, respectively.

The analysis treating distance as a continuous variable showed no evidence of association with risk.

## DISCUSSION

Contrary to other studies that reported childhood leukemia risk increasing with increasing wire code category (2–4), risk of acute lymphoblastic leukemia declined slightly with increasing wire code category (1) in our first report. In the present analysis, we separately evaluated the effects on acute lymphoblastic leukemia risk of distance from transmission lines, which generally carry a larger electrical load and produce larger magnetic fields, and distance from distribution lines. We failed to find an association of childhood acute lymphoblastic leukemia either with distance from the nearest power line within 40 m of a house or with an exposure index that takes into account the contribution of all nearby power lines. We were unable to demonstrate any risk for childhood acute lymphoblastic leukemia associated with living within 40 m of a transmission line, although few cases and controls actually lived this close.

Any wire code system has limitations. It is difficult to account for variations in wiring practices, so a code

**TABLE 2.** Risk of childhood acute lymphoblastic leukemia according to distance from either a transmission line or a three-phase primary distribution line to the main residence in a nine-state US study, 1989–1993

| | No. of cases* | No. of controls* | Odds ratio† | 95% confidence interval |
|---|---|---|---|---|
| Distance (m) to closest power line | | | | |
| >40 (0.091)‡ | 297 | 300 | 1.00§ | |
| 24–40 (0.089) | 43 | 37 | 1.23 | 0.75, 2.03 |
| 15–23 (0.152) | 36 | 34 | 1.01 | 0.60, 1.71 |
| 0–14 (0.207) | 29 | 34 | 0.79 | 0.46, 1.34 |
| Distance (m) to closest transmission line | | | | |
| >40 (0.103) | 395 | 385 | 1.00§ | |
| 34–40 (0.067) | 3 | 6 | 0.52 | 0.12, 2.18 |
| 24–35 (0.130) | 3 | 7 | 0.33 | 0.08, 1.39 |
| 0–23 (0.279) | 4 | 7 | 0.57 | 0.15, 2.13 |
| Distance (m) to closest distribution line | | | | |
| >40 (0.092) | 300 | 309 | 1.00§ | |
| 24–40 (0.089) | 42 | 32 | 1.49 | 0.88, 2.50 |
| 15–23 (0.160) | 38 | 31 | 1.15 | 0.67, 1.98 |
| 0–14 (0.208) | 25 | 33 | 0.75 | 0.43, 1.30 |

* Three cases and three controls were excluded because of missing information on family income.

† Odds ratios were adjusted by conditional logistic regression for gender, mother's educational level (<12 years, 12 years, some college, college graduate, or higher), and annual family income (<$20,000, $20,000–$29,000, $30,000–$39,000, $40,000–$49,000, or ≥$50,000).

‡ Numbers in parentheses, mean magnetic field level (μT) of homes at the indicated distance from the power line.

§ Reference group.

**TABLE 3. Risk of childhood acute lymphoblastic leukemia according to an index of electromagnetic field exposure in a nine-state US study, 1989–1993**

| Exposure index*,† | No. of cases‡ | No. of controls‡ | Odds ratio§ | 95% confidence interval |
|---|---|---|---|---|
| 0 (0.091)¶ | 297 | 300 | 1.00# | |
| I (0.092) | 47 | 34 | 1.30 | 0.80, 2.21 |
| II (0.143) | 26 | 36 | 0.72 | 0.41, 1.27 |
| III (0.213) | 35 | 35 | 0.98 | 0.59, 1.63 |
| Continuous variable (per 10 m) | 405 | 405 | 0.95 | 0.78, 1.16 |

* Exposure index was based on the distance to all transmission and primary three-phase distribution power lines near the child's house, as described in the text.

† Level I: >0 and <0.66 μT; level II: ≥0.66 and <1.30 μT; level III: ≥1.30 μT.

‡ Three case-control pairs were excluded because of missing information on family income.

§ Odds ratios were adjusted by conditional logistic regression for gender, mother's educational level (<12 years, 12 years, some college, college graduate, or higher), and annual family income (<$20,000, $20,000–$29,000, $30,000–$39,000, $40,000–$49,000, or ≥$50,000).

¶ Numbers in parentheses, mean magnetic field level (μT) of homes at the indicated index level.

\# Reference group.

designed for one region may be inapplicable in another (N. Wertheimer, Boulder, Colorado, personal communication, 1991). This highlights the need for field measurements that can be used to validate a wiring code system in geographic areas other than the one where it was developed (12, 13). In our main study (10) and in our present analysis, we found that time-weighted average magnetic field levels increased with increasing wire code classification and decreasing distance.

Some studies report a risk of childhood cancer or leukemia associated with distance from high-voltage installations and substations (14, 15), whereas others do not (16, 17, 18).

In our original paper, we used the Wertheimer-Leeper wire code classification scheme to evaluate risk of childhood acute lymphoblastic leukemia (1) because that is the metric that has been associated with risk in previous studies. As we collected data, we made sure to preserve the components of the Wertheimer-Leeper wire code classification so that we would be able to investigate the effects of distance and load separately and together. In this analysis, we found no suggestion that any of those variables are related to risk, and no evidence that children living near high-voltage power lines are at increased risk of acute lymphoblastic leukemia.

## ACKNOWLEDGMENTS

The authors thank Dave DeFrancesco and Tom Riley of Information Management Systems (Rockville, Maryland) for computer support.

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