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ORIGINAL CONTRIBUTIONS

# Los Angeles Study of Residential Magnetic Fields and Childhood Brain Tumors

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A measurement study of residential magnetic fields and brain tumors in children that was added onto an ongoing case-control interview study in Los Angeles County, California, included 298 children under age 20 years with a primary brain tumor diagnosed from 1984 to 1991 and 298 control children identified by random digit dialing. Magnetic fields were determined for all Los Angeles homes where these 596 children lived from conception to diagnosis (1,131 homes) by mapping and coding the wiring configurations outside the home and by taking a series of exterior spot and profile measurements. In addition, for a subset of subjects (35%; 211 homes) 24-hour measurements were taken in the child's room and one other room. Although measured fields are consistently highest in the highest of the five wire code categories, fields in homes in this category are much lower in Los Angeles than in Denver, where the code originated. Brain tumor risk appears not to relate to measured fields inside ($p$ for trend for child's room = 0.98) or outside ($p$ for trend for front wall = 0.82) the home. An apparent increase in risk among children living at diagnosis in homes with underground wiring appears to be an artifact introduced by using current controls for historical cases because this apparent excess risk disappeared in an analysis restricted to the later years of the study when cases and controls were accrued concurrently. Our study does not show an overall association of pediatric brain tumors with measured fields, with "very high" wiring configurations, or with any of several other potential sources of exposure, such as use of various electrical appliances, but the prevalence of high fields (>2 mG) and very high fields (>3 mG) in Los Angeles homes was too low to detect a moderate effect of the magnitude reported in other studies. *Am J Epidemiol* 1996;143:105–19.

brain neoplasms; case-control studies; child; electromagnetic fields

Brain tumors are the most common solid tumor in children and account for about 20 percent of pediatric cancers. Only certain rare, predisposing genetic conditions (such as neurofibromatosis) and ionizing radiation are established causes. Attempts to implicate other suspected risk factors in the etiology of this disease have been inconclusive, and several large, multicenter studies that are further investigating possible associations with maternal exposures during gestation and childhood exposures such as diet, *N*-nitroso compounds, prior medical conditions, and parental occupation are currently in progress. All are getting at least limited information on possible sources of exposure to magnetic fields—in most cases, just interview information on use of electric heating, electric blankets, and other appliances. A few are also investigating

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Abbreviation: ELF, extremely low frequency.

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ambient residential levels of magnetic fields that are likely to be the most important source of this exposure for many children.

The first study suggesting that children who died of brain cancer and other cancers were more likely to have lived in homes with nearby power lines indicative of high interior magnetic fields was conducted in Denver, Colorado, and codes were developed to enable classification of observable wiring configurations outside each home into five categories of likely interior fields (1). This scheme, which is known as the Wertheimer-Leeper classification, has since been used in several studies of various diseases in other areas of the United States. The Wertheimer-Leeper categories (from low to high) are "underground," "very low," "ordinary low," "ordinary high," and "very high."

Since the observations from the initial Denver study were published in 1979, literally hundreds of in vitro, animal, and epidemiologic studies have been conducted to investigate possible mechanisms by which magnetic fields might influence health and to define the spectrum of associations seen. Magnetic fields have not been shown to be genotoxic (2), but there is some evidence that they might act at a late stage to promote carcinogenesis (3). Among epidemiologists, the debate continues about whether associations seen with these relatively low-level exposures to extremely low-frequency fields (i.e., residential exposures to magnetic fields) are real or artifactual.

Three retrospective case-control studies have explored the possible relation between residential exposure to electromagnetic fields and childhood brain tumors (1, 4, 5). Because 93 percent of nervous system tumors are tumors of the brain, we use the term "brain tumor" for all. Because most brain tumors in children are malignant, the terms "brain tumor" and "brain cancer" are used interchangeably. Both studies done in Denver found a positive association when the Wertheimer-Leeper wire code was used as the indicator of the probable level of interior fields (1, 5), and a Swedish study found an association with proximity of the residence to 200-kV power lines (4). Of the two that measured fields, one found no increase in risk at fields greater than 2 mG (5), and the other found an odds ratio of 3.7 among children in homes with fields of greater than 3 mG outside the front door (4). More recently, three Scandinavian studies of cohorts of children living close to overhead high-voltage power lines have investigated the occurrence of brain tumors in these children and possible associations with calculations (based on distance from lines, line configuration, and historical or current loads on these lines) of likely residential exposures to magnetic fields (6–8). These studies did not find an increase in risk related to residence in homes with calculated fields of greater than 2 mG (if a child with neurofibromatosis who developed three primary nervous system tumors is counted as one case) (8). The one study that also showed risks separately for higher exposure levels reported an odds ratio of 6.0 for greater than 4 mG, but this finding was based on only two cases and one control, and there was no trend of increasing risk with increasing exposure (7). In summary, five of the six studies of residential electromagnetic fields and childhood cancer that reported findings for nervous system tumors separately included only a small number of children with nervous system tumors (66 or fewer); only the first Swedish study (4) had a sizable number (294 cases) and enough subjects in homes with very high (>3 mG) fields to have the power to clearly show an effect.

We report here on a Wertheimer-Leeper wire coding and magnetic field measurement study that was added on to a large retrospective case-control interview study of primary brain tumors among children in Los Angeles County, California. Also available for consideration are data from the interview study on maternal and childhood use of appliances. This interview study is part of a multicenter international study; the United States portion was conducted in 19 counties on the West Coast, in the Los Angeles, San Francisco, California, and Seattle, Washington, areas. Wertheimer-Leeper wire coding was also done in the Seattle area (9); measurement of magnetic fields was done only in Los Angeles County.

## MATERIALS AND METHODS

The present magnetic field assessment study was added to the Los Angeles portion of a multicenter, population-based interview study. In this parent study, a structured questionnaire was used to ask mothers and fathers about exposures and conditions thought likely to relate to pediatric brain tumor risk, including established risk factors such as ionizing radiation and predisposing genetic syndromes. Mothers were asked in some detail about various exposures during their pregnancy with the child, including possible sources of exposure to magnetic fields, such as those for water beds, electric blankets, radiant electric heat, and occupation, and a brief residence history was obtained. After review of pathology slides of histologically diagnosed cases (80 percent), 304 cases remained in the Los Angeles interview study.

The magnetic field measurement study was started about 2 years after the onset of the 5-year interview study. At this time, we recontacted mothers in order to add complete street addresses to the residence histories already collected, but we were unable to locate six of these mothers. Therefore, these six cases and the corresponding six controls were not included in the measurement study, resulting in a total of 596 children (298 case-control pairs).

## Subjects

*Cases.* Patients under age 20 years who were residents of Los Angeles County and had a benign or malignant primary tumor of the brain, cranial nerves, or cranial meninges (*International Classification of Diseases for Oncology* codes 191, 192.0, and 192.1) of any histologic type diagnosed during a period of 7 and a half years (January 1, 1984 through June 30, 1991) were eligible for inclusion. Only cases whose biologic mothers were available and able to be interviewed in either English or Spanish were included. Children of all races were eligible for inclusion, and we also interviewed the mothers and fathers of children who had died. The family of the case was required to have a telephone in the home because we were only able to identify control children whose families had telephones. Overall, mothers of 70 percent of eligible cases (86 percent of the mothers contacted about the study) participated in the interview study (table 1) (10).

*Controls.* A control group of children with the same range of birth years and the same distribution by sex as the cases was identified by random digit dialing (11). Telephone numbers were generated by randomly selecting an area code and a telephone exchange (first

**TABLE 1. Response rates for parent interview study and measurement outcome for all 2,000 residences where the 298 cases and 298 controls lived from conception to age at diagnosis of the case, childhood brain tumor/electromagnetic field study, Los Angeles County, California, 1984–1991**

| | Cases | | Controls | | Total |
|---|---|---|---|---|---|
| | No. | % | No. | % | |
| Interview study | | | | | |
| Eligible | 437 | 100 | 433 | 100 | 870 |
| Physician refused | 9 | | | | 9 |
| Untraceable | 57 | | 21 | | 78 |
| Moved out of area | 12 | | 2 | | 14 |
| Parents ill or dead | 7 | | 5 | | 12 |
| Parents contacted | 352 | | 405 | | 757 |
| Subject refused | 48 | | 101 | | 149 |
| Completed interview | 304 | 70 | 304 | 70 | 608 |
| Lost to follow-up for this study | 6 | | 6 | | 12 |
| Completed residential history | 298 | | 298 | | 596 |
| Electromagnetic field measurement study | | | | | |
| Total residences | 1,002 | 100 | 998 | 100 | 2,000 |
| Unassigned | 320 | 32 | 353 | 35 | 673 |
| Incomplete address | 124 | | 150 | | 274 |
| Out of Los Angeles County | 196 | | 203 | | 399 |
| California—adjacent county | 0 | | 1 | | 1 |
| California—nonadjacent county | 27 | | 19 | | 46 |
| Other state | 77 | | 88 | | 165 |
| Other country | 92 | | 95 | | 187 |
| Assigned | 682 | | 645 | | 1,327 |
| Unable to measure | 90 | 9 | 106 | 11 | 196 |
| Refusal | 4 | | 8 | | 12 |
| Dangerous area | 0 | | 1 | | 1 |
| File folder lost | 4 | | 2 | | 6 |
| No access | 7 | | 6 | | 13 |
| Nonexistent address | 23 | | 20 | | 43 |
| Unable to locate | 52 | | 69 | | 121 |
| Measured | 592 | 59 | 539 | 54 | 1,131 |

three digits of the seven-digit telephone number) from all exchanges in current use in the county. A randomly generated four-digit number was then added to the exchange. The telephone number was called until it was determined whether it was nonworking, a business, or a residence. Nine attempts (three during weekdays, three in the evening, and three on the weekend) were made before a number was classified a "no answer." When a residence was contacted, the household was screened according to a prescribed protocol, and data on eligible children were recorded. If the household had more than one telephone, a random procedure was used to either select or reject the household. Of 6,055 numbers called, 3,511 were not residences; 492 resulted in no answer after nine attempts; 215 refused to give a census (3.6 percent of the numbers called; 10.5 percent of the residences contacted), and we obtained a census at 1,837.

Upon completion of an interview with a case mother, a control child of the same sex who most closely matched the case on birth date (±1 year) was selected from the pool of potential random digit dial controls. A further consideration for recently diagnosed cases was that controls had to be at least as old at interview as the case was at diagnosis; a reference date, defined as the date when the control was the age of the case at diagnosis, was assigned for each control. Once a child was selected as a control, the other children in that family became ineligible to be selected. Interviews were obtained for 70 percent of the 433 eligible controls that we attempted to recontact for the interview study; this was 75.1 percent of control mothers contacted (table 1) (5).

## Measurement protocols

The goal of the exposure assessment was to estimate each child's exposure to magnetic fields in residences in Los Angeles County where the child had lived from conception to diagnosis (or reference date). For all residences, we planned to take measurements and assess wiring configurations outside the home, and for a subset of subjects whose current residence was also the residence at diagnosis or reference date, we planned to take interior measurements as well. Exterior measurements and maps of the wiring configurations were done first, usually without first contacting the residents, who had agreed at the time of the initial interview some months previously to participate in this further study. While making exterior observations and measurements, field technicians were never aware whether the child who had lived in a particular residence was a case or a control. On a very few occasions when making interior measurements, the technicians became aware that the child was a case.

Instruments used included the EMDEX, a Leeper meter, a static field magnetometer, and the STAR. The EMDEX (Model 100, Enertech Consultants, Campbell, California; and Model M, Electric Field Measurements, Inc., W. Stockbridge, Massachusetts) is an extremely low frequency (ELF) magnetic field monitor with a three-axis induction coil sensor, and a programmable data logger. The Leeper meter (42B-1 Milligaussmeter, Monitor Star Industries, Boulder, Colorado) is an ELF magnetic field survey meter with a single-axis induction coil sensor. The static field magnetometer (Model MAG-01, Bartington Instruments, Ltd., Oxford, United Kingdom), is a survey meter with a single-axis flux-gate sensor. The STAR (Dexsil Corporation, Hamden, Connecticut) is an ELF magnetic field monitor with a three-axis induction coil sensor, a mapping wheel, and a programmable data logger. The AutoCAD computer software (Autodesk, Inc., San Raphael, California) was used to make scale maps of the wiring around a home and to extract data about the wiring configurations onto a database computer file.

Exterior measurements involved adherence to a detailed protocol (10) and included measurements to assess the following: fields over the water meter and water pipes; static magnetic field; front door fields; and STAR magnetic field profiles, including front wall and perimeter of the dwelling. In addition, both a STAR profile map and a wiring configuration map were drawn according to explicit specifications. The full exterior measurement protocols were followed at all homes visited from January 1990 through June 1992. From July to December 1992, one field technician was employed part-time to visit and map the wiring configuration at all eligible residences that had not yet been visited.

Interior measurements were done in two phases. During the first phase, while case and control homes were still being visited for the parent interview study, the interviewer left EMDEX meters in the home. The meters were retrieved 24 hours later by technicians working on the electromagnetic field measurement study. Interior measurements of 163 homes were done in this way. During the second phase, after completion of the interview study, we sampled 48 additional current residences of subjects previously interviewed and took interior measurements, with the goal of achieving adequate representation across a given set of strata for all 211 homes with interior measurements; stratification variables included case or control status, Wertheimer-Leeper wire code, and exterior static magnetic field (10). Interior measurements included 24-hour EMDEX measurements taken every 10 seconds in the child's bedroom and in a second room where the child spent the most time (e.g., a television room). A Leeper meter was used to make sure that there was no localized magnetic field where the EMDEX was placed, and an explicit protocol for placement of the meter (e.g., under the child's bed) was followed. Interior magnetic fields were also measured by placing a magnetometer on a tripod in the child's bedroom.

During data collection, the accuracy of field measurements was assessed by periodic calibrations of the magnetic field instruments and regular monitoring of reliability and data integrity. Data for this study were collected on data sheets, maps, and computer files from the magnetic field dosimeters. Data sheets were formatted for direct data entry and stored in a secured filing system. Error checks were performed before data entry by the field technicians and after computerization by data-cleaning computer programs. The data collected by dosimeter were downloaded directly into a personal computer, quickly analyzed for preliminary statistics, and stored as a computer file backed up on magnetic tape.

Wiring maps of all overhead electrical transmission and distribution facilities within 150 feet of each residence were drawn by field technicians and checked for accuracy by a second person. Lists of the addresses were sent to the participating utilities, who provided their circuit maps for these neighborhoods. The field maps and utility maps were the basis for a computerized map of the exterior wiring of the residences, generated with the Facility Mapping System/AutoCAD software, which was adapted for this purpose in an earlier Los Angeles study (12) and constructs both a computer map file and a database of the wiring features needed to model the fields and blindly assign Wertheimer-Leeper codes.

### Statistical analysis

Tables 1 and 2 give information on the data available for analysis. The 298 matched pairs with complete residential histories obtained from interview with mothers formed the study population. The sample sizes for the analyses of particular exposure variables and potential confounders are smaller in some cases because we did not obtain complete measurement or interview information on every subject. We carried out both matched and unmatched analyses, and the results were virtually identical; unless otherwise indicated, we present the unmatched analysis.

Risk was assessed in relation to various exposure variables, including summary 24-hour EMDEX measurements, spot measurements, STAR profiles, and static fields, as well as wire code. Each exposure variable was categorized into four levels, based on the 50th, 75th, and 90th percentiles of its distribution among cases and controls combined; these cutpoints were chosen to facilitate comparison with previous studies (12). Tests for trend were performed by logistic regression, treating the exposure variable as continuous. For many subjects, exterior exposure measurements were available on more than one residence. For these subjects, a weighted average exposure over all measured homes was assigned, with weights proportional to the time spent in each residence. Analyses were also performed using a time-weighted average of all homes, assigning the overall mean to unmeasured homes. Since results from these two analyses were similar, only results from analyses using time-weighted averages excluding unmeasured homes are presented. Analysis of associations among different types of measurements used residences as the observational unit, whereas analyses relating measurements to brain tumor risk used subjects as the unit.

The sampling method (stratifying on case-control status, wire code, and geomagnetic field) used to select residences for interior measurement could in principle introduce bias into the sample means and relative risk estimates if it tended to produce larger sampling fractions in certain strata. To help measure the extent of any such bias, we adjusted the odds ratios to account for the sampling fraction in each stratum. Because the adjusted and the unadjusted odds ratios were almost identical, we show only those that are unadjusted.

To assess potentially different effects of exposure during different parts of the etiologic period, we studied the Wertheimer-Leeper classification of wiring configuration (1) with respect to three residences for each subject: the residence occupied at the beginning of the study period (9 months before birth), the residence occupied for the longest period of time, and the residence occupied at the end of the study period (at diagnosis or reference date). We called these "first," "longest," and "last" residences, respectively. For 79 percent of the subjects with wire code data for the first residence, this residence was also the child's residence at birth. Wire codes were available on 80 percent of the homes occupied during the 2 years before diagnosis or reference date.

For each subject, we computed a five-level index of socioeconomic status based on parental education and occupation (13). Mother's occupation (or father's if the mother had no job outside the home) correlated well with this index and was used when controlling for socioeconomic status in risk analyses. Factors related to risk, including demographic variables, parental occupation, and exposures during gestation, were studied univariately, using standard logistic regression models. Those factors found to relate to risk (two-tailed *p*

**TABLE 2. Number of cases and controls and types of exposure measurements available, childhood brain tumor/electromagnetic field study, Los Angeles County, California, 1984–1991**

| Measurement | Cases | Controls | Matched pairs |
|---|---|---|---|
| Wiring map | | | |
| First residence | 174 | 159 | 101 |
| Longest occupied residence | 240 | 220 | 175 |
| Last residence | 281 | 250 | 237 |
| Covering at least 80% of the etiologic period | 177 | 158 | 97 |
| Covering the last 2 years of the etiologic period | 275 | 245 | 226 |
| At least one residence | 292 | 269 | 265 |
| Spot measurements | | | |
| Front door—flat | 252 | 203 | 182 |
| Front door—linear | 251 | 203 | 181 |
| Water meter—flat, over | 243 | 199 | 176 |
| Water meter—flat, 6 feet away | 245 | 201 | 178 |
| Water meter—flat, other side | 244 | 201 | 178 |
| Water meter—linear, over | 242 | 199 | 175 |
| Water meter—linear, 6 feet away | 244 | 201 | 177 |
| Water meter—linear, other side | 243 | 201 | 177 |
| Exterior static magnetic field | 254 | 207 | 189 |
| Interior static magnetic field | 61 | 57 | 20 |
| At least one spot measurement | 255 | 208 | 190 |
| STAR* magnetic field profiles | | | |
| Front wall | 233 | 171 | 143 |
| Perimeter | 182 | 133 | 84 |
| Line 1 | 194 | 159 | 109 |
| Line 2 | 64 | 40 | 10 |
| At least one profile | 236 | 181 | 154 |
| EMDEX† 24-hour exposure measurements | | | |
| Child's room | 106 | 99 | 45 |
| Other room | 99 | 91 | 39 |
| At least 1 room | 110 | 101 | 47 |

* STAR Dexsil Corporation, Hamden, CT.

† EMDEX model 100, Enertech Consultants, Campbell, CA, and model M, Electric Field Measurements, Inc., West Stockbridge, MA.

value $\leq 0.10$) were controlled for in the analysis of risk by wire code.

Stepwise unconditional logistic regression was used to assess the combined effects of Wertheimer-Leeper code at last residence (four levels); building type at last residence (apartment/condominium vs. other); appliance use (prenatal or childhood use of radiant electric heat, electric blankets kept on all night, or water beds and childhood use of dial electric clocks); and maternal occupational exposure to high magnetic fields during the pregnancy. Interior field strength, considered as a continuous variable, was also added to the above model, but this model included few subjects because only about a third had interior measurements available. These sources of magnetic field exposure were determined a priori as the major sources that could be assessed in the Los Angeles study. Radiant heat and child's use of bedside dial clocks were both so uncommon that they failed to converge and were deleted from the model. Various models were constructed using different exposure periods (e.g., gestation, diagnosis or reference date, the entire 2-year period prior to diagnosis) and different ages at diagnosis (all ages combined, less than age 5 years, age 5 years and older). All models were run both unadjusted and stratified by sex, age, and year of diagnosis. The critical $p$ value for remaining in the multivariate model was 0.10.

## RESULTS

Table 1 shows the outcome for the 2,000 residences where cases and controls lived from conception to age at diagnosis of the case. Of the 673 residences not assigned to field personnel, 399 were not located in Los Angeles County (most were in Mexico) and 274 had addresses that were too incomplete to be usable (mother could not remember street number, etc.). Measurements were taken at 1,131 of the 1,327 addresses assigned to field personnel; no measurements were obtained at 196, usually because staff could not locate the residence (e.g., because it had been torn down) or the address turned out not to exist. Proportions of residences measured or lost for various reasons were similar for cases and controls.

Which measurements were obtained at each of the 1,131 residences varies considerably, as seen in table 2. More homes had wiring maps than any other field observation or measurement because toward the end of the study when resources were low a decision was made to get only a wiring map for homes that had not yet been visited. Somewhat more controls have no available wiring maps or measurements (see next paragraph), and a slightly higher number of control residences had incomplete (and, therefore, unusable) addresses (150 control residences vs. 124 case residences). These differences resulted in a consistently somewhat smaller number of control residences than case residences with any given measurement. Nevertheless, wire codes covering 100 percent of the potentially relevant etiologic period (from conception to diagnosis) were available for 48 percent of the cases and 43 percent of the controls.

The higher proportion of controls with no electromagnetic field measurements is largely attributable to the fact that 16 controls who lived in Los Angeles at the time of random digit dial calling did not live in the county during the period from conception to reference date and thus had no eligible residences. This circumstance resulted from the decision to include cases diagnosed up to 4 and a half years prior to the start of the interview study. Given this decision, which was justified in order to include a sufficient number of cases of this rare cancer, other methods of control selection (e.g., from the neighborhoods where cases lived at diagnosis) would also have resulted in identification of some controls who were not county residents during the period of interest. Because cases who had moved out of the county after diagnosis were eligible for inclusion in the interview study, we decided not to exclude controls who had moved into the county since the reference date because such an exclusion might have resulted in a bias toward greater stability of residence among controls, which had been a problem in an earlier study (3). Therefore, these 16 controls were included in the parent interview study and in demographic and appliance use analyses, but were excluded from all wire code and measurement analyses because they had no eligible residences to measure. Such somewhat different inclusion criteria for controls compared with cases seemed valid for the interview study but are valid for the present study only if the wire code distribution of in-migrants is the same as that of out-migrants. Wire code distributions in these two groups of migrants (in and out) are unknown, but might be expected to be different, particularly because in-migrants to Los Angeles during this period included many Latinos from Mexico and Central America. In our study, Latinos born in Mexico and Central America were less likely than those of other ethnicities to live in homes with underground wiring (2 vs. 15 percent; analysis based on father's birthplace).

Although control identification by random digit dial began late in 1988, controls were interviewed from April 1989 onward. Thus, for the period from 1989 to 1991 cases and controls accrued concurrently, but cases accrued from 1984 through 1988 were matched to controls accruing from 1989 onward who were assigned appropriate earlier reference dates. Informative comparisons of results for the two periods are possible. For example, in an analysis by birthplace with US birth as the baseline category, the odds ratios for foreign born were 0.6 (95 percent confidence interval 0.3–1.1) for cases diagnosed before 1989 and 1.2 (95 percent confidence interval 0.5–2.5) for those born in 1989 or later.

By design, the distributions of cases and controls by sex and age were similar (table 3). However, the distributions of the two groups by parents' ethnicity and socioeconomic status varied in analyses using all subjects or just those with reference years in the earlier versus later time periods. Overall, a higher proportion of control mothers and fathers were Latino. However, in a comparison of subjects with reference dates prior to 1989, the proportion of fathers who were Latino was similar for the two groups, and a lower proportion of case mothers compared with control mothers were Latina (table 3). The distributions by socioeconomic status show that a somewhat higher proportion of controls were in the highest social class, and this finding is similar in comparisons using all subjects or either time period subgroup.

Means of selected interior and exterior measurements for each of the five wire code categories are shown in table 4. For all measurements except static magnetic field, magnetic field levels are clearly highest in homes with very high magnetic configurations and in general increase over the five categories. This increase is not always monotonic, but becomes more so if very low and ordinary low are combined into a single category. Median 24-hour EMDEX measurements in homes with very high wire codes are 1.1 and 1.3 in the child's bedroom and the other room, respec-

**TABLE 3. Demographic information for 298 cases and 298 matched controls with interview and residential study data, childhood brain tumor/electromagnetic field study, Los Angeles, County, California, 1984–1991**

| Item | All years | | Before 1989* | | 1989 and after† | |
|---|---|---|---|---|---|---|
| | Cases (%) | Controls (%) | Cases (%) | Controls (%) | Cases (%) | Controls (%) |
| Sex | | | | | | |
| Male | 54.4 | 54.4 | 52.4 | 52.4 | 57.9 | 57.9 |
| Female | 45.6 | 45.6 | 47.6 | 47.6 | 42.1 | 42.1 |
| Age at diagnosis or reference (years) | | | | | | |
| 0–4 | 39.9 | 39.6 | 39.8 | 39.3 | 40.2 | 40.2 |
| 5–9 | 25.2 | 25.5 | 27.8 | 28.3 | 20.6 | 20.6 |
| 10–14 | 18.5 | 19.1 | 18.9 | 18.9 | 17.8 | 19.6 |
| ≥15 | 16.4 | 15.8 | 13.6 | 13.6 | 21.5 | 19.6 |
| Mother's ethnicity | | | | | | |
| Latina | 45.6 | 49.3 | 41.9 | 53.4 | 52.3 | 42.1 |
| Non-Latina white | 39.6 | 35.9 | 43.5 | 31.9 | 32.7 | 43.0 |
| Non-Latina black | 8.7 | 8.1 | 8.4 | 8.4 | 9.4 | 7.5 |
| Asian | 5.0 | 5.4 | 5.8 | 4.7 | 3.7 | 6.5 |
| Other and unknown | 1.0 | 1.3 | 0.5 | 1.6 | 1.9 | 0.9 |
| Father's ethnicity | | | | | | |
| Latino | 38.9 | 47.0 | 37.2 | 50.3 | 42.1 | 41.1 |
| Non-Latino white | 43.0 | 35.9 | 45.6 | 33.0 | 38.3 | 41.1 |
| Non-Latino black | 9.1 | 6.7 | 8.9 | 6.3 | 9.4 | 7.5 |
| Asian | 3.7 | 4.0 | 3.7 | 3.7 | 3.7 | 4.7 |
| Other and unknown | 5.4 | 6.4 | 4.7 | 6.8 | 6.5 | 5.6 |
| Socioeconomic status | | | | | | |
| I (high) | 9.1 | 13.1 | 8.4 | 12.6 | 10.3 | 14.0 |
| II | 17.1 | 16.8 | 20.4 | 16.8 | 11.2 | 16.8 |
| III | 32.2 | 31.5 | 29.3 | 30.4 | 37.4 | 33.6 |
| IV | 26.8 | 24.8 | 28.8 | 26.2 | 23.4 | 22.4 |
| V (low) | 14.8 | 13.8 | 13.1 | 14.1 | 17.8 | 13.1 |

* 191 case-control pairs.
† 107 case-control pairs.

tively; thus, fields in "very high" homes in Los Angeles appear to be only about half as high as those with very high fields in other geographic areas, such as Denver and Sweden. These low fields are not an artifact of season of measurement because measurements taken during all seasons were low (10). Only those homes at the 90th percentile and above of measured interior fields had very high (>3 mG) fields (4.1 and 3.1 for the child's room and the other room, respectively). The mean front door flat measurements at apartments or condominiums (includes apartments, condos, duplexes, and townhouses) was 0.87 mG compared with a mean of 0.74 mG for all other types of residences (single-family houses, either single or multiple story; $p = 0.14$).

Risks of developing a brain tumor in relation to various measures of magnetic fields at the last residence (i.e., residence at diagnosis or reference date) are shown in table 5. For each, the baseline is taken as those residences in the 0–49th percentile for the measurement type under consideration, and odds ratios are calculated for the 50–74th, 75–89th, and 90–100th percentiles. For the mean, median, and 90th percentiles of all 24-hour EMDEX measurements of the child's room and the other room, odds ratios appear elevated among that small subset of children in homes at the 90th percentile and above of each of these metrics; these are the only groups of Los Angeles homes where fields are as high as those in Denver homes with high wire codes. Similarly, odds ratios were elevated when the mean fields in the child's room or the other room were greater than 3 mG, whether all children or just those with reference date in 1989 or later were considered; again, the number of children living in homes with these very high fields was small (table 5). Elevated brain tumor risk was not consistently seen for homes in the 90th percentile of various exterior measurements (e.g., spot measure-

TABLE 4. **Measured interior and exterior magnetic fields (in mG) for each of five wire code categories, childhood brain tumor/electromagnetic field study, Los Angeles County, California, 1984–1991**

| Measurement | Total | Wire code category | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | UG* | | VL* | | OL* | | OH* | | VH* | |
| | | No. | Level | No. | Level | No. | Level | No. | Level | No. | Level |
| EMDEX† 24 hr | | | | | | | | | | | |
| Child's room mean | | | | | | | | | | | |
| Mean | 204 | 28 | 0.78 | 25 | 0.76 | 53 | 1.04 | 78 | 1.18 | 20 | 1.79 |
| Median | 204 | 28 | 0.47 | 25 | 0.57 | 53 | 0.43 | 78 | 0.60 | 20 | 1.08 |
| 10th percentile | 204 | 28 | 0.15 | 25 | 0.16 | 53 | 0.16 | 78 | 0.22 | 20 | 0.41 |
| 90th percentile | 204 | 28 | 1.82 | 25 | 2.05 | 53 | 1.86 | 78 | 3.60 | 20 | 4.12 |
| % >2 mG | 204 | 28 | 7.1 | 25 | 12.0 | 53 | 9.4 | 78 | 14.1 | 20 | 35.0 |
| Other room mean | | | | | | | | | | | |
| Mean | 189 | 25 | 0.63 | 23 | 1.96 | 46 | 1.05 | 75 | 1.17 | 20 | 1.44 |
| Median | 189 | 25 | 0.41 | 23 | 0.70 | 46 | 0.53 | 75 | 0.65 | 20 | 1.30 |
| 10th percentile | 189 | 25 | 0.21 | 23 | 0.32 | 46 | 0.23 | 75 | 0.25 | 20 | 0.49 |
| 90th percentile | 189 | 25 | 0.96 | 23 | 6.64 | 46 | 1.99 | 75 | 2.33 | 20 | 3.10 |
| % >2 mG | 189 | 25 | 8.0 | 23 | 17.4 | 46 | 8.7 | 75 | 12.0 | 20 | 15.0 |
| Means of spot measurements | | | | | | | | | | | |
| Front door | | | | | | | | | | | |
| Flat | 835 | 62 | 0.49 | 108 | 0.58 | 230 | 0.63 | 342 | 0.73 | 93 | 1.68 |
| Linear | 833 | 62 | 0.56 | 108 | 0.71 | 229 | 0.76 | 341 | 0.89 | 93 | 1.84 |
| Over water meter | | | | | | | | | | | |
| Flat | 791 | 52 | 0.65 | 99 | 1.01 | 219 | 1.62 | 334 | 1.51 | 88 | 1.68 |
| Linear | 792 | 52 | 0.82 | 99 | 1.42 | 218 | 2.09 | 334 | 1.90 | 88 | 2.31 |
| STAR‡ profile means | | | | | | | | | | | |
| Front wall mean | 658 | 55 | 0.63 | 83 | 0.54 | 178 | 0.67 | 273 | 0.77 | 69 | 1.62 |
| Perimeter mean | 427 | 34 | 0.56 | 48 | 0.61 | 118 | 0.67 | 187 | 0.85 | 40 | 1.93 |
| Line 1 median | 529 | 30 | 0.89 | 45 | 0.64 | 154 | 0.75 | 230 | 0.86 | 70 | 2.08 |
| Static magnetic fields | | | | | | | | | | | |
| Exterior | 857 | 64 | 482.98 | 110 | 473.38 | 233 | 477.51 | 354 | 474.58 | 96 | 472.09 |
| Interior | 122 | 16 | 492.37 | 13 | 455.42 | 34 | 465.63 | 48 | 463.50 | 11 | 491.35 |

* UG, underground; VL, very low; OL, ordinary low; OH, ordinary high; VH, very high.

† EMDEX model 100, Enertech Consultants, Campbell, CA, and model M, Electric Field Measurements, Inc., West Stockbridge, MA.

‡ STAR Dexsil Corporation, Hamden, CT.

ments at the front door, STAR front wall profiles, and static fields), and no trends relating risk and milligauss level were evident. Results were similar when the first or longest residence or the time-weighted average of each measurement was used for subjects with measurements for more than one residence as described above. In addition, findings changed little when case and control means weighted by the inverse of the sampling fraction of the strata were used for interior EMDEX comparisons. Brain tumor risk did not relate to whether exterior static fields were in or out of resonance (not shown here; a home is said to be "in resonance" when the exterior static magnetic field falls within either of the two intervals (334.5–425.5) or (460.5–551.5) (10)).

Table 6 shows analyses of risk by wire code. Wire code is the observation available for the greatest number of subjects, is the indicator most often associated with brain tumor risk in earlier studies, and is suggested as possibly the best indicator of long-term magnetic field exposure. It is usual in such analyses to use underground as the referent category, but because our data showed an overall excess of underground residences among cases (39 cases vs. 18 controls lived in homes with underground wiring at reference date) and because there were too few subjects in this group to form a stable referent category, we decided to use the very low and ordinary low categories combined as baseline. In an analysis using all subjects, there appeared to be an increase in risk related to living at diagnosis in a home with underground wiring; this excess was evident in analyses using first and longest residences and was seen among children diagnosed before and after age 5 years. The excess was apparent in both crude and adjusted analyses. However, when analysis was restricted to cases and controls with di-

**TABLE 5. Risk of developing a brain tumor before age 20 years in relation to various residential measurements of magnetic fields at last residence, unmatched analysis, Los Angeles, California, 1984–1991**

| mG range* | No. of cases | No. of controls | All years OR† | All years 95% CI† | Before 1989 OR | Before 1989 95% CI | 1989 and after OR | 1989 and after 95% CI |
|---|---|---|---|---|---|---|---|---|
| 24-hour EMDEX‡ | | | | | | | | |
| Child's room | | | | | | | | |
| Mean | | | | | | | | |
| 0.10–0.58 | 48 | 53 | 1.0 | | 1.0 | | 1.0 | |
| 0.59–1.06 | 29 | 22 | 1.5 | 0.7–3.0 | 1.0 | 0.4–2.8 | 2.7 | 0.9–7.9 |
| 1.07–2.48 | 16 | 15 | 1.2 | 0.5–2.8 | 1.4 | 0.4–5.0 | 0.7 | 0.2–2.4 |
| 2.49–9.60 | 13 | 9 | 1.6 | 0.6–4.5 | 1.6 | 0.4–6.8 | 1.6 | 0.4–5.7 |
| *p* for trend | | 0.79 | | | 0.79 | | 0.95 | |
| >2 mG§ | 16 | 13 | 1.2 | 0.5–2.8 | 1.3 | 0.4–4.9 | 0.9 | 0.3–2.6 |
| >2.5 mG | 13 | 9 | 1.4 | 0.5–3.8 | 1.4 | 0.4–5.8 | 1.1 | 0.3–3.8 |
| >3 mG | 12 | 7 | 1.7 | 0.6–5.0 | 1.7 | 0.4–7.9 | 1.4 | 0.4–5.4 |
| Median | | | | | | | | |
| 0.09–0.51 | 47 | 54 | 1.0 | | 1.0 | | 1.0 | |
| 0.52–1.02 | 29 | 22 | 1.5 | 0.7–3.2 | 1.4 | 0.5–3.8 | 2.3 | 0.8–6.6 |
| 1.03–2.03 | 19 | 12 | 1.8 | 0.7–4.5 | 1.8 | 0.5–6.3 | 1.5 | 0.5–5.0 |
| 2.04–10.40 | 11 | 11 | 1.2 | 0.4–3.2 | 1.3 | 0.3–5.5 | 1.0 | 0.3–3.5 |
| *p* for trend | | 0.98 | | | 0.83 | | 0.78 | |
| 90th percentile | | | | | | | | |
| 0.12–0.78 | 44 | 57 | 1.0 | | 1.0 | | 1.0 | |
| 0.79–1.64 | 32 | 19 | 2.2 | 1.0–4.6 | 2.5 | 0.9–7.0 | 3.6 | 1.2–11.0 |
| 1.65–4.42 | 17 | 14 | 1.6 | 0.7–3.8 | 2.6 | 0.7–9.5 | 1.9 | 0.5–6.8 |
| 4.43–15.80 | 13 | 9 | 1.9 | 0.7–5.3 | 1.8 | 0.4–8.0 | 1.6 | 0.5–5.7 |
| *p* for trend | | 0.60 | | | 0.65 | | 0.96 | |
| Other room | | | | | | | | |
| Mean | | | | | | | | |
| 0.11–0.62 | 46 | 48 | 1.0 | | 1.0 | | 1.0 | |
| 0.63–1.21 | 27 | 20 | 1.4 | 0.7–3.0 | 0.7 | 0.2–1.9 | 2.3 | 0.8–6.9 |
| 1.22–2.32 | 12 | 17 | 0.7 | 0.3–1.9 | 0.7 | 0.2–2.6 | 1.0 | 0.3–3.1 |
| 2.33–12.53 | 14 | 6 | 2.4 | 0.8–7.8 | 1.1 | 0.2–6.0 | 2.6 | 0.7–10.0 |
| *p* for trend | | 0.39 | | | 0.95 | | 0.45 | |
| >2 mG | 15 | 8 | 1.9 | 0.7–5.1 | 1.7 | 0.4–7.9 | 1.8 | 0.5–6.0 |
| >2.5 mG | 14 | 6 | 2.3 | 0.8–7.2 | 2.2 | 0.4–13.4 | 2.3 | 0.6–8.1 |
| >3 mG | 10 | 5 | 1.9 | 0.6–6.8 | 1.6 | 0.2–10.5 | 1.9 | 0.4–8.0 |
| Median | | | | | | | | |
| 0.12–0.59 | 48 | 47 | 1.0 | | 1.0 | | 1.0 | |
| 0.60–1.02 | 24 | 22 | 1.1 | 0.5–2.3 | 0.6 | 0.2–1.9 | 2.2 | 0.8–6.3 |
| 1.03–1.99 | 14 | 15 | 0.9 | 0.4–2.3 | 0.9 | 0.3–3.0 | 1.2 | 0.3–4.1 |
| 2.00–11.09 | 13 | 7 | 1.8 | 0.6–5.6 | 0.8 | 0.1–4.9 | 2.2 | 0.6–7.8 |
| *p* for trend | | 0.46 | | | 1.00 | | 0.54 | |

**Table continues**

agnosis or reference year in 1989 or later, the numbers of cases and controls who live in homes with underground wiring are similar (11 vs. 12), and little increase in risk associated with underground wiring is seen (table 6). Thus, for the period 1989–1991, it is appropriate to use underground homes in the referent category. When underground alone is used, the minimally adjusted odds ratio for homes in very high category is 2.0 compared with odds ratios of 2.1 and 1.7, respectively, in analyses using homes in the underground and very low categories combined or those in the underground, very low, and ordinary low categories as the baseline. As shown in table 6, when homes in the very low and ordinary low categories combined are used as the referent in an analysis restricted to subjects with reference year in 1989 or later, there is no excess risk associated with living in homes with underground wiring in the crude or minimally adjusted analyses and only a slight excess after adjustment for socioeconomic status.

Table 7 shows risk related to appliance use. From the beginning of the interview study, we asked each

**TABLE 5. Continued**

| mG range* | No. of cases | No. of controls | All years | | Before 1989 | | 1989 and after | |
|---|---|---|---|---|---|---|---|---|
| | | | OR | 95% CI | OR | 95% CI | OR | 95% CI |
| 90th percentile | | | | | | | | |
| 0.12–0.86 | 45 | 50 | 1.0 | | 1.0 | | 1.0 | |
| 0.87–1.73 | 28 | 18 | 1.7 | 0.8–3.8 | 0.9 | 0.3–2.6 | 2.4 | 0.8–7.2 |
| 1.74–3.72 | 12 | 17 | 0.8 | 0.3–2.0 | 0.5 | 0.1–1.8 | 1.0 | 0.3–3.2 |
| 3.73–22.36 | 14 | 6 | 2.6 | 0.8–8.4 | 1.9 | 0.3–12.2 | 2.6 | 0.7–9.8 |
| *p* for trend | | 0.28 | | | 0.82 | | 0.45 | |
| Spot measurements | | | | | | | | |
| Front door–flat | | | | | | | | |
| 0.01–0.42 | 120 | 87 | 1.0 | | 1.0 | | 1.0 | |
| 0.43–0.82 | 56 | 45 | 0.9 | 0.5–1.5 | 0.9 | 0.5–1.7 | 1.2 | 0.5–2.9 |
| 0.83–1.50 | 36 | 27 | 1.0 | 0.5–1.8 | 0.8 | 0.4–1.5 | 2.3 | 0.6–7.9 |
| 1.51–8.00 | 16 | 23 | 0.5 | 0.2–1.1 | 0.6 | 0.3–1.6 | 0.4 | 0.1–1.3 |
| *p* for trend | | 0.29 | | | 0.89 | | 0.10 | |
| >2 mG§ | 13 | 15 | 0.7 | 0.3–1.5 | 0.7 | 0.3–1.9 | 0.5 | 0.1–2.1 |
| >2.5 mG | 11 | 10 | 0.9 | 0.3–2.3 | 1.3 | 0.4–4.2 | 0.2 | 0.03–1.7 |
| >3 mG | 7 | 6 | 0.9 | 0.3–3.2 | 2.6 | 0.5–13.7 | 0.1 | 0.01–1.4 |
| STAR‖ profiles | | | | | | | | |
| Front wall mean | | | | | | | | |
| 0.06–0.48 | 91 | 75 | 1.0 | | 1.0 | | 1.0 | |
| 0.49–0.82 | 57 | 28 | 1.7 | 0.9–3.0 | 1.7 | 0.8–3.4 | 2.3 | 0.9–6.0 |
| 0.83–1.45 | 28 | 22 | 1.1 | 0.5–2.1 | 0.7 | 0.3–1.6 | 1.8 | 0.6–5.5 |
| 1.46–6.01 | 19 | 18 | 0.9 | 0.4–1.9 | 0.8 | 0.3–1.9 | 2.0 | 0.4–9.2 |
| *p* for trend | | 0.82 | | | 0.86 | | 0.27 | |
| >2 mG§ | 13 | 8 | 1.2 | 0.5–3.3 | 1.2 | 0.4–3.5 | 1.9 | 0.2–2.05 |
| >2.5 mG | 10 | 5 | 1.5 | 0.5–5.1 | 1.1 | 0.3–3.8 | | 3 ca. 0 co. |
| >3 mG | 5 | 4 | 0.9 | 0.2–4.1 | 0.5 | 0.1–2.5 | | 2 ca. 0 co. |
| Static fields | | | | | | | | |
| Exterior | | | | | | | | |
| 332.20–477.74 | 112 | 91 | 1.0 | | 1.0 | | 1.0 | |
| 477.75–489.39 | 65 | 39 | 1.4 | 0.8–2.3 | 1.5 | 0.8–2.7 | 0.9 | 0.4–2.2 |
| 489.40–503.63 | 25 | 37 | 0.6 | 0.3–1.0 | 0.5 | 0.3–1.1 | 0.5 | 0.2–1.3 |
| 503.64–637.38 | 29 | 16 | 1.5 | 0.7–3.0 | 1.6 | 0.7–3.7 | 1.0 | 0.3–3.3 |
| *p* for trend | | 0.27 | | | 0.10 | | 0.38 | |
| Interior | | | | | | | | |
| 303.43–468.53 | 31 | 27 | 1.0 | | 1.0 | | 1.0 | |
| 468.54–480.08 | 14 | 16 | 0.8 | 0.3–2.0 | 0.8 | 0.2–3.4 | 0.5 | 0.2–1.8 |
| 480.09–497.03 | 7 | 11 | 0.6 | 0.2–1.8 | 6.2 | 0.5–72.1 | 0.1 | 0.02–0.6 |
| 497.04–589.25 | 9 | 3 | 2.6 | 0.6–13.7 | 5.6 | 0.8–37.6 | 2.6 | 0.2–27.8 |
| *p* for trend | | 0.46 | | | 0.06 | | 0.38 | |

* The first interval in each group is the range from the 0th to the 49th percentile, the second is the range from the 50th to the 74th percentile, the third is the range from the 75th to the 89th percentile, and the fourth is the range from the 90th to the 100th percentile.

† OR, odds ratio; CI, confidence interval.

‡ EMDEX model 100, Enertech Consultants, Campbell, CA, and model M, Electric Field Measurements, Inc., West Stockbridge, MA.

§ For each of the categories >2, >2.5, and >3 mG, the baseline is all subjects not in that category.

‖ STAR Dexsil Corporation, Hamden, CT.

mother about her use during pregnancy or the child's use of a number of appliances, including electric blankets, water beds, electric clocks (digital and dial assessed separately), electric heat (radiant or other), microwave ovens, and ham radios. One association of note, although it is of only borderline statistical significance, is a twofold increase in risk among children whose mothers slept on electrically heated water beds during the pregnancy. Those living in homes with underground wiring during the 2 years before diagnosis were not more likely to use electric blankets or water beds. For a subset of subjects (those interviewed after these questions were added to the questionnaire), data are also available on the child's use of hair dryers,

**TABLE 6. Risk in relation to wire code at diagnosis, childhood brain tumor/electromagnetic field study, Los Angeles County, California, 1984–1991**

| Wire code | No. of cases | % | No. of controls | % | Unadjusted | | Minimally adjusted* | | Fully adjusted† | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | OR‡ | 95% CI‡ | OR | 95% CI | OR | 95% CI |
| Combined | | | | | | | | | | |
| UG‡ | 39 | 14 | 18 | 7 | 1.9 | 1.0–3.6 | 2.0 | 1.1–3.7 | 2.3 | 1.2–4.3 |
| VLCC‡/OLCC‡ | 114 | 41 | 102 | 41 | 1.0 | | 1.0 | | 1.0 | |
| OHCC‡ | 97 | 35 | 106 | 42 | 0.8 | 0.6–1.2 | 0.8 | 0.5–1.2 | 0.8 | 0.6–1.2 |
| VHCC‡ | 31 | 11 | 24 | 10 | 1.2 | 0.6–2.1 | 1.2 | 0.7–2.2 | 1.2 | 0.6–2.2 |
| Total | 281 | | 250 | | | | | | | |
| Reference year before 1989 | | | | | | | | | | |
| UG | 28 | 16 | 6 | 4 | 4.2 | 1.6–10.8 | 4.4 | 1.7–11.5 | 4.3 | 1.6–11.2 |
| VLCC/OLCC | 70 | 39 | 63 | 41 | 1.0 | | 1.0 | | 1.0 | |
| OHCC | 62 | 35 | 66 | 43 | 0.8 | 0.5–1.4 | 0.9 | 0.5–1.4 | 0.9 | 0.5–1.4 |
| VHCC | 18 | 10 | 17 | 11 | 1.0 | 0.5–2.0 | 1.0 | 0.5–2.1 | 1.0 | 0.5–2.2 |
| Total | 178 | | 152 | | | | | | | |
| Reference year 1989 and after | | | | | | | | | | |
| UG | 11 | 11 | 12 | 12 | 0.8 | 0.3–2.0 | 0.8 | 0.3–2.1 | 1.2 | 0.5–3.4 |
| VLCC/OLCC | 44 | 43 | 39 | 40 | 1.0 | | 1.0 | | 1.0 | |
| OHCC | 35 | 34 | 40 | 41 | 0.8 | 0.4–1.5 | 0.7 | 0.4–1.4 | 0.8 | 0.4–1.6 |
| VHCC | 13 | 13 | 7 | 7 | 1.6 | 0.6–4.5 | 1.7 | 0.6–4.7 | 1.6 | 0.6–4.8 |
| Total | 103 | | 98 | | | | | | | |

* Adjusted for age, sex, and birth year.

† Adjusted for age, sex, and birth year plus: socioeconomic status and maternal waterbed use for combined group, for the before 1989 subset, and for the 1989 and after subset.

‡ OR, odds ratio; CI, confidence interval; UG, underground; VLCC, very low current configuration; OLCC, ordinary low current configuration; OHCC, ordinary high current configuration; VHCC, very high current configuration.

curling irons, black-and-white televisions, and baby monitors. None of these were related to risk.

Results of multivariate logistic regression analyses that simultaneously considered various indicators of possibly high electromagnetic field exposure (see description of statistical methods) were generally unremarkable. The model that included the most subjects (232 cases and 183 controls) considered these exposures at the last residence (i.e., at diagnosis or reference date). None of the variables (Wertheimer-Leeper wire code, building type, or use of electrically heated bed, i.e., water bed or electric blanket left on all night) entered the model at the $p = 0.10$ level. This was also true in general for the other models.

We also performed analyses that considered for each subject the total number of sources of high magnetic field exposure (home with very high magnetic field, apartment/condominium, electrically heated bed, and radiant heat). For those analyses that considered exposures during gestation, we also considered maternal occupations with a high electromagnetic field. These analyses also considered age of child at diagnosis (<5; ≥5 years), and we attempted to estimate odds ratios associated with being positive on one electromagnetic source or on two or more (10, pp. 125–126). The estimates were unreliable because fewer than half of the subjects had data available on all four (or five) sources under consideration.

The relations between residential mobility and both case/control status and wiring configuration were examined by looking at wiring code of longest residence in relation to percentage of the etiologic period and number of years spent there. Neither result indicates a relation between mobility and wiring code. Analyses of tumor risk by number of residences and tumor risk by proportion of etiologic period in the longest residence showed no association of case/control status with mobility (10).

## DISCUSSION

Overall, our findings in Los Angeles County do not show an increase in risk of developing a childhood brain tumor with increasing exposure to magnetic fields, as assessed by 24-hour measurements, spot measurements, or Denver Wertheimer-Leeper wiring classification. However, when analyses are restricted to very high exposures inside the home (>3 mG),

TABLE 7. **Risk of developing a brain tumor before age 20 years in relation to appliance use during pregnancy and childhood, unmatched analysis, Los Angeles County, California, 1984–1991**

| | No. of cases | % | No. of controls | % | All years | | Before 1989 | | 1989 and after | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | OR* | 95% CI* | OR | 95% CI | OR | 95% CI |
| Pregnancy | | | | | | | | | | |
| Electric blanket | 20 | 7 | 18 | 6 | 1.2 | 0.6–2.2 | 1.3 | 0.6–2.9 | 0.9 | 0.2–3.0 |
| Electric water bed | 23 | 8 | 12 | 4 | 2.1 | 1.0–4.2 | 2.4 | 0.9–6.2 | 1.9 | 0.6–5.9 |
| Electric clock | 143 | 58 | 144 | 60 | 1.0 | 0.8–1.3 | 1.1 | 0.8–1.4 | 0.8 | 0.4–1.3 |
| Dial | 48 | 20 | 41 | 17 | 1.1 | 0.7–1.8 | 0.8 | 0.4–1.7 | 1.4 | 0.7–2.9 |
| Electric heat | 26 | 11 | 17 | 7 | 1.6 | 0.8–3.0 | 1.8 | 0.8–4.2 | 1.2 | 0.4–3.4 |
| Radiant | 3 | 1 | 2 | 1 | 1.3 | 0.2–8.3 | 1.5 | 0.1–16.9 | 1.0 | 0.1–16.9 |
| Microwave | 54 | 30 | 52 | 25 | 1.4 | 0.9–2.3 | 2.9 | 1.3–6.7 | 0.9 | 0.4–1.7 |
| Ham radio | 2 | 1 | 0 | 0 | | | | | | |
| Child | | | | | | | | | | |
| Electric blanket | 11 | 4 | 9 | 3 | 1.2 | 0.5–3.0 | 1.4 | 0.4–5.3 | 1.0 | 0.3–3.8 |
| Electric water bed | 8 | 3 | 4 | 1 | 2.0 | 0.6–6.8 | 1.8 | 0.4–7.6 | 3.0 | 0.3–31.8 |
| Electric clock | 54 | 22 | 67 | 28 | 0.7 | 0.4–1.0 | 0.8 | 0.4–1.5 | 0.5 | 0.3–1.0 |
| Dial | 14 | 6 | 18 | 8 | 0.6 | 0.3–1.4 | 0.7 | 0.2–1.9 | 0.6 | 0.2–1.8 |
| Electric heat | 28 | 11 | 21 | 9 | 1.3 | 0.7–2.4 | 1.4 | 0.6–3.2 | 1.4 | 0.6–3.3 |
| Radiant | 6 | 2 | 4 | 2 | 1.4 | 0.4–5.0 | 1.3 | 0.1–16.4 | 1.5 | 0.3–7.1 |
| Microwave | 106 | 58 | 119 | 57 | 1.0 | 0.6–1.5 | 1.8 | 0.9–3.3 | 0.5 | 0.3–0.9 |
| Ham radio | 2 | 1 | 1 | 0.5 | 2.1 | 0.2–23.7 | | | | |
| Hair dryer | 55 | 51 | 63 | 44 | 1.2 | 0.7–2.1 | 1.9 | 0.6–5.6 | 0.9 | 0.4–1.8 |
| Curling iron | 16 | 15 | 17 | 12 | 1.0 | 0.4–2.5 | 1.5 | 0.2–10.1 | 0.8 | 0.3–2.5 |
| Black/white television | 20 | 20 | 34 | 26 | 0.7 | 0.4–1.4 | 1.1 | 0.3–3.7 | 0.5 | 0.2–1.1 |
| Baby monitor | 7 | 8 | 14 | 11 | 0.6 | 0.2–0.7 | 0.4 | 0.02–7.4 | 0.5 | 0.2–1.7 |

* OR, odds ratio; CI, confidence interval.

results are consistent with the hypothesis of elevated risk, although the numbers of subjects living in homes with very high interior fields was too small to show an effect clearly. Among earlier studies, only the Tomenius study (4) had sufficient numbers of subjects living in homes with very high fields to examine this association meaningfully.

Our study was designed to have statistical power of 80 percent to detect a relative risk of 2.0 at the 5 percent level, assuming a very high prevalence of 10 percent. In our study, the prevalence of homes with very high magnetic fields was 10.4 percent, yet brain tumor risk was not significantly increased among all children living in these homes. In Denver and Sweden, homes with high wire codes have interior fields that are generally about two times higher than those in homes with very high codes in Los Angeles. In addition, in some of the earlier studies, such as the second Denver study, fields may have been underestimated by the different meter that was used (5). What is clear is that the Wertheimer-Leeper codes do a better job of differentiating high- and low-field homes in Denver than in Los Angeles (5, 10, 12). Although we did not have sufficient statistical power to detect a significant effect, the risk for very high wire code was elevated in the subset with reference year 1989 or later, the period during which cases and controls were accrued concurrently. Furthermore, our Los Angeles study suggests that risk is increased in homes with interior 24-hour EMDEX measurements at the 90th percentile and above; these are the only homes in Los Angeles in which magnetic fields are as high as fields found in Denver homes with high wire codes. Consistent with earlier studies, our study suggests that fields are higher in apartments than in single-family residences, but in both types of residences, fields in Los Angeles are lower than those in Denver and Scandinavia.

Because ambient magnetic fields in homes in Los Angeles are low, it may be that some Los Angeles children get most of their exposure from other sources. We did not obtain information on ambient fields in other locations where children spend time, such as day-care facilities and schools. We did get information during the interview on use by the mother and child of various electrical appliances. Such appliances are a potentially important source of exposure to magnetic fields, particularly when they are used in proximity to the brain (fields drop off rapidly with distance) and for prolonged periods. Radiant electric heat (e.g., from coils under the floor) and electrically heated beds are potentially major sources of exposure. Dial electric clocks at the head of the bed might also be important if the child slept near one, although we do not see such an association. Use of dial electric clocks during pregnancy is not likely to have involved much exposure to the fetal brain, and we see no association in our data.

We also see no association with radiant electric heat, which is used in only 1–2 percent of Los Angeles homes. In contrast to Savitz et al. (14), we found little elevation in risk for prenatal electric blanket use, but our results did suggest a twofold increase in risk related to maternal use of water beds that was of borderline statistical significance. Electric blankets and water beds were each used by about 6 percent of the mothers in our study. Electric blankets involve exposures that are 2 or more times higher than those from water beds (15–17), but unlike blankets, which are used only for a few months of the year in Los Angeles, water beds are used year round.

When findings from recently completed studies of the association between residential magnetic field exposure and childhood brain tumors are also considered, results must now be described as mixed, and there continues to be much debate about whether or not the association is real and possibly causal (18). Wertheimer and Leeper (1) found a statistically significant association between childhood brain cancer incidence and wiring configuration, with odds ratios of between 2 and 3. They made no other measurements of magnetic field exposure. Savitz et al. (5) also found a significant association with wiring configuration, but no association with measured magnetic field. Tomenius (4) found significant associations with magnetic field measurements taken outside the front doors of residences and with proximity to transmission lines. In all three of these early case-control studies, fields in homes in the very high exposure category were two or more times higher than fields in Los Angeles homes in this category. Consistent with our results, the three recent cohort studies found no overall association with magnetic fields as estimated from historical loads in transmission lines, from proximity to transmission lines, or from spot measurements (6–8); however, as in our study, when analyses were restricted to homes with very high fields (>3 or 4 mG) risk did appear to be elevated, but estimates are unstable due to the small numbers of subjects.

We found an excess of residences with underground wiring among cases. However, the excess disappeared when the analysis was restricted to those years of the study when cases and controls were accrued concurrently. We conclude, therefore, that the apparent excess risk related to living in homes with underground wiring is an artifact attributable to bias in the control selection process. Because of the rapid increase in the Latino population of Los Angeles County during the 1980s, controls who were assigned reference years earlier than 1989 were selected from a population with a higher proportion of Latinos than the population from which cases diagnosed prior to 1989 originated.

The proportion of homes of our brain tumor cases and controls classified as very high was similar to that of controls in the Los Angeles childhood leukemia study (table 8) (12). Because our case group includes all cases in the county population over a specified period, this similarity suggests that control selection in the leukemia study was not biased in such a way as to underestimate the true proportion of homes with very high magnetic fields in Los Angeles County, as has been suggested by some critics. Although the leukemia study, like ours, included children in Los Angeles County, it matched controls to cases on telephone prefix and studied children generally younger and from earlier years than children in our study.

Unlike earlier studies (4, 5), our study found no relation between case/control status and residential mobility. We also did not find any relation of mobility with wire code, contrary to findings in Columbus, Ohio (19).

Our study, which is the largest study to date of residential exposure to magnetic fields and brain cancer in children, does not resolve the controversy surrounding this hypothesized association. We conclude that in Los Angeles County, where ambient fields in homes are relatively low compared with other geographic areas, overhead power lines appear unrelated to risk, but that risk may still prove to be increased in

**TABLE 8.** **Distributions of cases and controls in childhood leukemia (1980–1987) and childhood brain tumor (1984–1991) studies by wire code in the longest residence, Los Angeles County, California**

| Wire code | Leukemia | | | | Childhood brain tumor | | | |
|---|---|---|---|---|---|---|---|---|
| | No. of cases | % | No. of controls | % | No. of cases | % | No. of ccontrols | % |
| UG* | 11 | 5.2 | 11 | 5.4 | 29 | 12.1 | 13 | 5.9 |
| VLCC* | 20 | 9.5 | 27 | 13.2 | 28 | 11.7 | 30 | 13.6 |
| OLCC* | 58 | 27.5 | 75 | 36.6 | 81 | 33.8 | 55 | 25.0 |
| OHCC* | 80 | 37.9 | 68 | 33.2 | 82 | 34.2 | 97 | 44.1 |
| VHCC* | 42 | 19.9 | 24 | 11.7 | 20 | 8.3 | 25 | 11.4 |

* UG, underground; VLCC, very low current configuration; OLCC, ordinary low current configuration; OHCC, ordinary high current configuration; VHCC, very high current configuration.

the small proportion of homes where fields are exceptionally high (>3 mG).

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