American Journal of Epidemiology
Copyright © 1995 by The Johns Hopkins University School of Hygiene and Public Health

Vol 141, No 4
Printed in U.S.A.

Residential Exposure to Magnetic Fields and Risk of Canine Lymphoma

John S. Reif,[1] Kimberly S. Lower,[1] and Gregory K. Ogilvie[2]

A hospital-based case-control study was conducted to determine whether residential exposure to magnetic fields increased risk for canine lymphoma in pet dogs. Cases were patients at a veterinary teaching hospital with histologically confirmed lymphoma diagnosed between 1987 and 1990. Hospital controls with other forms of cancer were obtained by frequency matching on zip code and year of diagnosis. Information regarding the dog's activity patterns, residence history, and exposure to potential confounders was obtained by telephone interview. Wire codes and magnetic fields were measured at the homes at diagnosis of 93 cases and 137 controls. When exposure was categorized into two levels (high or very high wire codes compared with low, very low, or buried lines), the risk was elevated (odds ratio (OR) = 1.6, 95% confidence interval (CI) 0.9–2.9) and increased (OR= 1.8, 95% CI 0.9–3.4) after adjustment for potential confounders. Dogs that lived in homes with very high current codes had the highest risk (OR = 6.8, 95% CI 1.6–28.5). Moderate, imprecise increases in risk (odds ratios of 1.5–1.9) were found for residence in a home with a sidewalk (plumbing), backyard, or front yard magnetic field of 2.0 mG or greater, but not for indoor measurements at this level. Risk increased among dogs that spent more than 25% of the day outdoors. Laboratory and observational studies of dogs as an animal model for the effects of magnetic fields are recommended. *Am J Epidemiol* 1995;141:352–9.

dog diseases; electromagnetic fields; lymphoma

The relation between exposures in the home to extremely low frequency (50–60 Hz) electric and magnetic fields and the occurrence of childhood cancer has been the subject of intense recent interest. An increased risk for childhood leukemia has been the most consistent finding in studies of childhood cancer and residential exposure to magnetic fields (1–4). More limited evidence exists for an increase in leukemia risk among adults exposed to residential magnetic fields (5, 6). However, a number of studies have reported an increased risk for lymphoid malignancies in adults associated with occupational exposures to electric and magnetic fields (7). Therefore, we hypothesized that an association may exist between exposure to magnetic fields and lymphoid cancer in pet dogs that live in a residential environment.

Canine lymphoma is a common hematopoietic cancer of dogs for which the etiology remains unknown. Most cases are classified histologically as high grade lymphomas (8); some dogs have a leukemic phase during the course of their illness. Because canine lymphoma shares some features of human leukemia and non-Hodgkin's lymphoma (9), the effects of environmental exposures have been evaluated in several epidemiologic studies of this animal model of lymphoid cancer (10–12).

In this paper, we report the findings of a case-control study of canine lymphoma and exposure to residential magnetic fields. If an association between magnetic fields and lymphoid cancer risk exists in a second species, the biologic plausibility of the increased risks reported for leukemia in humans would be strengthened. Further, identification of an animal model for lymphoid cancer after exposure to magnetic fields under natural conditions could lead to elucidation of biologic mechanisms in the laboratory.

MATERIALS AND METHODS

Cases and controls

Eligibility for inclusion as a case was determined through a two-stage process. Initially, all histologically confirmed cases of canine lymphoma diagnosed between January 1, 1987 and December 30, 1990 on the oncology service at the Colorado State University Veterinary Teaching Hospital were eligible for study.

Received for publication April 14, 1994, and in final form September 19, 1994.

Abbreviations: CI, confidence interval; OR, odds ratio.

[1] Department of Environmental Health, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO

[2] Department of Clinical Sciences, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO.

Reprint requests to Dr. John S. Reif, Department of Environmental Health, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, CO 80523.

Telephone interviews were conducted with owners to assess exposure to several environmental risk factors as part of a larger study of canine lymphoma. From the pool of 125 interviewed case owners, residences within 150 miles (241.5 km) of the hospital at the time of diagnosis (n = 109) were considered eligible for evaluation of magnetic fields and determination of wire codes. Dogs that had lived at their residence for less than one year at the time of diagnosis were excluded.

Hospital-based controls were selected from among dogs with other histologically confirmed malignant neoplasms diagnosed during the same time period. From a pool of 370 interviewed owners of controls, patients that did not meet the established criteria for distance (150 miles (241.5 km)) and duration of residence (one year) were excluded. To create a control-to-case ratio of 1.5:1, 164 frequency-matched controls were then selected randomly from within strata of year of diagnosis and zip code, or city if matching could not be completed for zip code.

Interview

The initial telephone interview conducted with each dog owner sought information concerning the dog's duration of residence and activity patterns. Exposure to potential confounders such as insect repellents, home insecticides, and lawn herbicides was ascertained. A history of diagnostic x-ray procedures and medications was obtained. An occupational history for household members focused on industries where exposure to pesticides, uranium ore, and other chemicals could have resulted in secondary exposure to the subject from contamination of clothing or visiting the job site. The use of an electric blanket by the owner and dog was assessed. Family income data were collected to control for socioeconomic status.

Residence

The residence at the time of diagnosis was evaluated for each subject by an investigator blinded to case or control status. Wire codes were categorized at all homes where the original owner remained in residence and granted permission. An in-home evaluation of magnetic fields was also sought from owners who remained at their original address. As found in other studies (2, 3), some homes were no longer occupied by the subject. In such instances, the wire code was categorized and the outdoor magnetic field was evaluated at the sidewalk (plumbing field). No attempt was made to evaluate homes lived in prior to diagnosis.

Measurement of wire codes

The wiring configuration for each home was coded according to the system of Wertheimer and Leeper (1), as recently modified (13). This predictor of long-term magnetic fields exposure is based on type of wire near the house (high tension, 3-phase primary, or secondary), thickness of a 3-phase primary (if present), and proximity of the home to the wires. The code also recorded whether the secondary was first or second span (first span secondaries issue directly from the transformers and carry the most current), and the number of homes supplied by the secondary wire ("drops"). Secondary wires were recorded as open or spun. Open secondaries are generally found in older neighborhoods and produce greater loss of current with higher magnetic fields (13). However, to maintain adherence to the original Wertheimer-Leeper system (1), spun and open secondaries were coded identically. Homes were coded as buried wire, very low current configuration, ordinary low current configuration, ordinary high current configuration, and very high current configuration to correspond with previous studies (1–3). Distances were measured from the power line to the edge of the first populated room of the house; i.e., to a bedroom, living room, or kitchen. A diagram was drawn that detailed wire types and distances from the house for all wires within 130 feet (39 m), and a wire code was assigned. The wiring diagrams were reviewed by a second observer in a blinded manner, and any discrepancies in coding were resolved.

Measurement of magnetic fields

Maximum magnetic fields were measured in milligauss (mG) with the use of a model 42B-1 portable Exploratory AC Milligaussmeter (Monitor Industries, Boulder, Colorado) with a hand-held coil. Outdoor readings were taken using a flat frequency response (equal meter readings for equal mG fields). Maximum fields were determined by rotating the hand-held coil slowly at three mutually perpendicular angles. The predominant angle of the maximum magnetic field was recorded as vertical or horizontal. The plumbing field was measured by holding the detection coil perpendicularly to the sidewalk at a standard level and walking along the sidewalk until the meter indicated an abrupt rise and fall at the level of the incoming water main pipe/water meter. Plumbing fields are produced by current that escapes from power lines to travel through the ground and through plumbing systems, to which many homes are grounded (13).

Indoor magnetic fields were measured in the room where the dog had spent most of its time. Measurements were taken in a standing position at mid-room, away from large appliances, with the meter loop held at a standard level. Measurements were also taken in the area of the room usually occupied by the dog approximately one foot (0.3 m) above the ground, or at mid-room if the owner could not recall a specific area. The effect of turning household appliances on or off was not evaluated. Magnetic fields were also measured in the backyard, at the location where the dog spent most of its time, or at mid-yard if the owner did not indicate a specific location.

Analysis

Odds ratios (14) with approximate 95 percent confidence intervals (15) were calculated from contingency tables to estimate risk. The Mantel extension chi-square test was applied to evaluate trends in the odds ratios across exposure strata of wire codes and magnetic fields (16). Unconditional logistic regression was used to obtain the maximum likelihood point estimate of the odds ratio and the 95 percent confidence interval in multivariate analyses (17). Age, sex, owner's socioeconomic status, geographic area, years of residence, and proportion of time spent outdoors were included as potential confounders unless otherwise stated.

RESULTS

Evaluation of magnetic fields or wire codes was completed for 93 of the 109 eligible cases of canine lymphoma that lived within 150 miles (241.5 km) of the hospital at diagnosis (85.3 percent). Among controls, magnetic field or wire code evaluation was completed for 137 of the 164 eligible residences (83.5 percent). One owner of a case and four owners of control dogs refused to participate. The remainder were not evaluated because the original owners had moved and the addresses could not be verified.

The distribution of control dogs by major diagnostic category was a reflection of the referral pattern for the hospital oncology service. The major sites represented included bone (24.1 percent), soft tissue sarcomas (18.2 percent), oral and pharyngeal (13.9 percent), nasal (9.5 percent), and skin and connective tissue (6.6 percent). All other sites (urinary tract, gastrointestinal, breast, etc.) comprised less than 6 percent each.

The distributions of cases and controls by geographic area was generally similar, as would be anticipated from the group matching process. A higher proportion of controls (21.3 percent) than cases (16.3 percent) lived in a household where the income was less than $25,000. Persons of lower socioeconomic status might be less likely to own purebred dogs, and a corresponding small difference in proportion of purebreds between cases (68.8 percent) and controls (65.0 percent) was seen. Controls were older than cases (mean age 10.4 vs. 8.4 years) and had lived at the residence at diagnosis for approximately one year longer than had the cases (6.8 vs. 5.4 years).

The relation between risk of canine lymphoma and residential wire code configuration was examined (table 1). A high or very high wire code configuration was associated with a moderate increase in risk in all analyses; a small increase in the effect estimate was consistently observed after controlling for age, sex, socioeconomic status, geographic area, duration of residence, and time spent outdoors. Exposure to pesticides, diagnostic x-rays, or electric blankets was not found to exert confounding as ascertained by little or no divergence from the crude odds ratio in multivariate analyses.

When the wire codes were dichotomized into high and low categories by combining the very high and high categories, the adjusted odds ratio was 1.8 (95 percent confidence interval (CI) 0.9–3.4). Comparison of the high category with buried wire code in a three-level analysis yielded an adjusted point estimate of the odds ratio of 2.1 (95 percent CI 1.0–4.4). Stratification of the wire codes into five levels showed a significant increase in risk only for the highest exposure code (very high current configuration) (crude odds ratio (OR) = 6.8, 95 percent CI 1.6–28.5). A monotonic increase in crude risk across wire code strata was not observed (p value for trend = 0.1).

In situations where wire code was determined by proximity to a first-span secondary wire, an increase in lymphoma risk was associated with "open" secondaries irrespective of distance (as opposed to "spun" secondaries, in which the three phases are wrapped around each other). The odds ratio for open secondaries was 1.9 (95 percent CI 0.8–4.6) with buried wires serving as the reference category, while the odds ratio for spun secondaries was 0.9 (95 percent CI 0.3–2.7). Similarly, risk was associated with the 3-phase thick primary (OR = 2.1, 95 percent CI 0.9–5.0), as opposed to the thin primary (OR = 0.6, 95 percent CI 0.2–2.0) wiring configuration, irrespective of distance to the home. The analyses of specific wiring configurations were generally based on small sample sizes; therefore, only crude odds ratios are presented.

Outdoor measurements of the plumbing magnetic fields were made at the sidewalk for 89 of the 93 cases and 136 of the 137 controls (table 2). A sidewalk magnetic field of 2.0 mG or higher was associated with a slightly increased risk (OR = 1.5), but the confidence intervals were wide. Backyard magnetic field measurements provided a similar, but imprecise

TABLE 1. Canine lymphoma risk in relation to wire code at residences occupied at time of diagnosis: Colorado, 1987–1990

Wire code	Cases (n = 93)	Controls (n = 137)	Crude odds ratio	95% CI*	Adjusted† odds ratio	95% CI
Two-level wire code						
Low‡	66	109	1.00	–	1.00	–
High§	27	28	1.59	0.87–2.93	1.77	0.91–3.41
Three-level wire code						
Buried	37	63	1.00	–	1.00	–
Low‖	29	46	1.07	0.68–1.99	1.20	0.62–2.32
High§	27	28	1.64	0.84–3.20	2.06	0.96–4.42
Mantel χ^2 for trend = 1.90, p = 0.17						
Five-level wire code						
Buried	37	63	1.00	–	1.00	–
Very low	10	14	1.22	0.49–3.02	1.46	0.53–4.04
Low	19	32	1.01	0.50–2.04	1.19	0.56–2.54
High	19	26	1.24	0.61–2.56	1.48	0.66–3.32
Very high	8	2	6.81	1.63–28.5	13.43	1.76–102.7
Mantel χ^2 for trend = 2.42, p = 0.12						

* CI, confidence interval.
† Adjusted for age, sex, socioeconomic status, area, years lived in home, and percent of time spent outdoors.
‡ Buried, very low, or low wire code.
§ High or very high wire code.
‖ Very low or low wire code.

risk estimate (OR = 1.5) for 2.0 mG and higher, which increased to 2.2 after adjustment for confounding in multivariate analysis. Front yard measurements provided somewhat higher risk estimates up to 3.1 (95 percent CI 1.2–8.4) but were highest for the intermediate exposure category of 0.65 to 2.0 mG.

Assessments of magnetic fields at the residences of case and control dogs were made indoors for 39 (42 percent) of the cases and 71 (52 percent) of the controls. Indoor magnetic field measurements were made in the middle of the room most frequently occupied by the dog as well as nearer the floor, to reflect exposure to the dog. As shown in table 2, indoor measurements showed no evidence of an increased risk. There was little evidence of a dose-response trend in any of the analyses of magnetic field measurements.

The estimated risks for lymphoma associated with wire code and magnetic field data were stratified according to duration of residence at the home (table 3). After adjustment for age, the estimates of risk for wire code were homogeneous across the strata of residential occupancy. The risk estimates for magnetic field exposure of 2.0 mG and above were also similar (OR = 1.8–1.9) across the 2- and 4-year duration of occupancy strata but increased to 3.2 for the group of dogs exposed for at least 6 years.

Risk estimates were examined according to the proportion of time spent by the dog outdoors (table 4). Effect modification was evident in this analysis; dogs that spent more than 25 percent of their time outdoors showed increases in risk for exposure to high current configuration wire codes (OR = 2.1) and to magnetic fields of at least 2.0 mG measured in the backyard (OR = 2.9) or as a plumbing field at the sidewalk (OR = 2.2). Risks were substantially reduced or absent for dogs that spent less than 25 percent of their time outdoors. The number of dogs with measured indoor magnetic fields of at least 2.0 mG was too small to permit meaningful stratified analysis.

DISCUSSION

Residential exposure to magnetic fields has been associated with increased risk for childhood leukemia and other childhood cancers in studies conducted in the United States (1–3) and Europe (4). The original findings of the Wertheimer and Leeper study (1) have been confirmed in some studies, but not in other studies. Nondifferential misclassification in one "negative" study (18) may have biased risk estimates toward the null (2, 19) and small numbers of children who lived close to overhead power lines limited the statistical power of another study (20). As a result, uncertainty about the effects of residential exposure to magnetic fields on human cancer risk persists.

TABLE 2. Canine lymphoma risk in relation to measured magnetic fields at residence occupied at time of diagnosis: Colorado, 1987–1990

Exposure (mG)	Cases (n = 93)	Controls (n = 137)	Crude odds ratio	95% CI*	Adjusted† odds ratio	95% CI
Sidewalk plumbing field						
0–<0.65	61	103	1.00	–	1.00	–
0.65–<2.00	20	24	1.41	0.72–2.76	1.42	0.69–2.92
≥2.00	8	9	1.50	0.55–4.09	1.50	0.50–4.52
Missing	4	1				
Mantel χ^2 for trend = 1.22, p = 0.27						
Backyard						
0–<0.65	27	47	1.00	–	1.00	–
0.65–<2.00	13	32	0.71	0.32–1.58	0.78	0.31–1.92
≥2.00	7	8	1.52	0.48–4.67	2.21	0.59–8.35
Missing	46	50				
Mantel χ^2 for trend = 0.40, p = 0.53						
Front yard						
0–<0.65	26	43	1.00	–	1.00	–
0.65–<2.00	16	10	2.65	1.06–6.63	3.12	1.16–8.36
≥2.00	8	7	1.89	0.62–5.80	1.71	0.51–5.78
Missing	43	77				
Mantel χ^2 for trend = 1.45, p = 0.22						
Indoors						
0–<0.65	20	36	1.00	–	1.00	–
0.65–<2.00	15	26	1.04	0.45–2.41	1.40	0.54–3.60
≥2.00	4	9	0.80	0.22–2.95	0.94	0.22–3.92
Missing	54	66				
Mantel χ^2 for trend = 0.097, p = 0.76						

* CI, confidence interval.

† Adjusted for age, sex, socioeconomic status, area, years lived in home, and percent of time spent outdoors.

The study reported here adds support to the studies of childhood cancer and exposure to magnetic fields. The methods used for exposure assessment in this study of an "animal sentinel" were generally similar to those employed previously (1–3). The finding of a 60 percent increase in risk among dogs that lived in homes with a high versus low current configuration is consistent with the odds ratios of 1.5 found by Savitz et al. (2) for childhood cancer in Denver and 1.7 for leukemia calculated from the data reported by London et al. (3) in Los Angeles. Similarly, stronger associations with the very high wiring configuration were found in the current study (crude OR = 6.8), in the original study by Savitz et al. (2), where a risk of 5.2 for occupancy 2 years prior to diagnosis was reported, and in the reanalysis of the Denver data using a modified wire code (21).

The wiring configuration outside the home has been suggested to represent a reliable surrogate measure of long-term exposure to residential magnetic fields (21). In studies where both wire codes and magnetic fields have been measured, stronger associations have been observed with wire codes than with either spot or 24-hour measurements of indoor magnetic fields (2, 3). In the study reported here, positive but imprecise associations were observed with measured magnetic fields of 2.0 mG or greater. Crude odds ratios between 1.5 and 1.9 were found for back and front yard magnetic fields of 2.0 mG and above, but not for indoor measurements above 2.0 mG. The findings for indoor relative to outdoor measurements may be due in part to the transient sources of magnetic field "noise" induced by the use of appliances, etc., within the home. In this study, as in several other reports (1–3, 22, 23), wire codes were correlated with spot measurements of magnetic fields inside and outside the home, providing some evidence of their validity as a surrogate marker. Others have argued that wire codes may actually be a better marker of residential exposures over a long period than contemporaneous measures of magnetic fields (21, 22).

TABLE 3. Canine lymphoma risk in relation to two-level wire codes and measured magnetic fields, by duration of occupancy*: Colorado, 1987–1990

Duration of occupancy	Exposure		Odds ratio†	95% CI‡
	Two-level wire code§			
	Low	High		
2+ years				
Controls	100	28	1.00	–
Cases	63	25	1.47	0.75–2.86
4+ years				
Controls	84	21	1.00	–
Cases	50	18	1.71	0.76–3.85
6+ years				
Controls	65	17	1.00	–
Cases	31	11	1.63	0.60–4.45
	Magnetic field (mG)‖			
	<2.0	≥2.0		
2+ years				
Controls	118	9	1.00	–
Cases	77	8	1.86	0.71–4.86
4+ years				
Controls	96	8	1.00	–
Cases	60	7	1.80	0.59–5.50
6+ years				
Controls	76	5	1.00	–
Cases	35	6	3.23	0.85–12.30

* Cases and controls restricted by number of years lived at residence.
† Adjusted for age by logistic regression.
‡ CI, confidence interval.
§ Low = buried, very low, and low wire code; high = high and very high wire code.
‖ Magnetic field measured at sidewalk.

TABLE 4. Canine lymphoma risk in relation to two-level wire code and magnetic fields stratified by percent of time spent outdoors: Colorado, 1987–1990

Exposure	% of time spent outdoors			
	≤25		>25	
	OR	95% CI*	OR	95% CI*
Two-level wire code†				
Low	1.00	–	1.00	–
High	1.28	0.56–2.93	2.09	0.84–5.17
Backyard magnetic field (mG)				
<2.0	1.00	–	1.00	–
≥2.0	1.05	0.22–4.92	2.93	0.63–13.75
Sidewalk magnetic field (mG)				
<2.0	1.00	–	1.00	–
≥2.0	0.86	0.19–3.77	2.21	0.57–8.60

* CI, confidence interval.
† Low = buried, low, or very low; high = high or very high.

In studies of childhood cancer, no relation or weak associations were found with spot measurements (2, 4) or 24-hour measurements (3) of magnetic fields made indoors. In this study, positive associations were found with outdoor measurements of magnetic fields. In this respect, the effect modification observed with respect to the proportion of the day spent outdoors by the subject is of interest. Risk estimates increased to 2.0 and above among dogs exposed to high wire codes or to sidewalk and backyard magnetic fields of 2.0 mG and above that had spent more than 25 percent of the day outdoors. The magnetic fields induced by overhead wires may differ from those found indoors. Appliances and electrical wiring within the home may result in magnetic fields that differ in character, spike patterns, or duration from those encountered outdoors.

Following an analysis scheme similar to Savitz et al. (3), we examined the risk of canine lymphoma after restriction of cases and controls according to duration of occupancy. As previously reported (3), no evidence of a dose-response effect of increasing duration of occupancy was observed for a dichotomized wire code (ordinary high current configuration and very high current configuration). On the other hand, the age-adjusted odds ratio for a sidewalk magnetic field of 2.0 mG was stable through 4 years of occupancy but rose to 3.2 among dogs that had resided in the home for at least 6 years. Lack of residential mobility among cases has been suggested as a source of bias in one previous study of residential exposure to magnetic fields (24). In this study, the mean duration of residence for cases and controls was similar and represented 66.6 percent of the mean age of cases and 65.4 percent of that of controls at the time of diagnosis. Because the longevity of dogs is shorter than that of humans, one can assess a larger proportion of the lifetime exposure to magnetic fields by examining the residence at the time of diagnosis. Further, the proportion of dogs that lived in homes with a high current wire code was identical (23 percent) in the subset of cases and controls for which indoor magnetic field measurements were available and in the entire study population, which suggests that the estimates were not affected by residential mobility.

Confounding was not found to be an important source of bias in this study. Socioeconomic status was determined from family income; controls were more likely to live in a household where the income was less than $25,000. Cases were slightly more likely to live in Denver than were controls. These variables could be related to neighborhood wiring patterns. The effects of these potential sources of bias were taken into account in the multivariate analyses. After controlling for age, sex, owner's socioeconomic status, geographic area, duration of residence, and proportion of time spent outdoors, risks were similar to crude estimates or adjusted upward. Other potential risk factors, such as exposures to pesticides, diagnostic radiation, and electric blankets, were not found to exert a confounding effect.

Local environmental conditions, such as the age of the neighborhood and traffic density, were not evaluated directly. An increased risk associated with open secondary wires, generally found in older neighborhoods (13), was observed. However, open and spun secondaries were used to classify wire code in only 38 of the 230 homes evaluated. Therefore, the data cannot be used to make a general inference about the age of the home and risk of canine lymphoma.

Selection bias may have been introduced in this study by choosing a cancer control group. The use of a cancer control group has a number of important advantages, particularly the reduction of information bias due to differential recall (25). The choice of a cancer control group may be especially advantageous in this hospital-based setting, where referral patterns may influence the distribution of important predictor variables. The referral patterns for lymphoid and other cancers are similar in this hospital. However, selection bias may be introduced if the exposure of interest also increases risk for other cancers. In this instance, the effect of the distortion is to bias the effect estimate toward the null (26). Evidence that this type of selection bias may have occurred comes from studies of childhood cancer that show increased risk estimates for several forms of cancer, including leukemia, brain cancer, and soft tissue sarcoma (2). The control group used in this study did not contain dogs with brain cancer, but did include cases of breast cancer and sarcomas of bone and soft tissues. If magnetic fields act as a general cancer promoter as suggested by some investigators (1), then the effect of the use of a cancer control group in this study would have been to underestimate the risk for lymphoma.

The findings presented above add to the evidence that spontaneous canine neoplasms such as lymphoma may be useful models for studies of environmentally induced cancer. As shown in a number of previous studies (12, 27, 28), dogs may act as a "sentinel" species for the effects of environmental exposures on the risk of analogous human diseases. The shortened life-span of pet dogs and restricted daily and long-term residential mobility may reduce the misclassification of environmental exposures that often plagues studies in humans. Therefore, investigators may wish to consider laboratory-based studies of the effects of magnetic fields on melatonin secretion, immune surveillance, and neuroendocrine function in dogs. Additional studies of canine lymphoma and other cancers, reproductive outcomes, and neurobehavioral disorders could be undertaken. Further laboratory and observational studies of dogs as an animal model for the effects of magnetic fields are recommended.

ACKNOWLEDGMENTS

The authors thank Dr. Nancy Wertheimer for training in the measurement of magnetic fields and wire codes and for performing quality assurance with these data. They also thank Drs. Alan Luke and Jenifer Lloyd for interviewing and technical assistance.

REFERENCES

1. Wertheimer N, Leeper E. Electrical wiring configurations and childhood cancer. Am J Epidemiol 1979;109:273–84.
2. Savitz DA, Wachtel H, Barnes FA, et al. Case-control study of childhood cancer and exposure to 60-Hz magnetic fields. Am J Epidemiol 1988:128:21–38.
3. London SJ, Thomas DC, Bowman JD, et al. Exposure to residential electric and magnetic fields and risk of childhood leukemia. Am J Epidemiol 1991;134:923–7.
4. Feychting M, Ahlbom A. Magnetic fields and cancer in children residing near Swedish high-voltage power lines. Am J Epidemiol 1993;138:467–81.
5. Coleman MP, Bell CMJ, Taylor HL, et al. Leukaemia and residence near electricity transmission equipment: a case-control study. Br J Cancer 1989;60:793–8.
6. Youngson JHAM, Clayden AD, Myers A, et al. A case-control study of adult haematological malignancies in relation to overhead powerlines. Br J Cancer 1991;63:977–85.
7. Savitz DA, Calle EE. Leukemia and occupational exposure to electromagnetic fields: review of epidemiologic surveys. J Occup Med 1987;29·47–51.
8. Carter RF, Valli VEO, Lumsden JH. The cytology, histology and prevalence of cell types in canine lymphoma classified according to the National Cancer Institute Working Formulation. Can J Vet Res 1986;50:154–64.
9. Squire RA, Melby EC. Naturally occurring canine and feline lymphomas as biomedical models. In: Animal models for biomedical research. National Academy of Sciences report no. 1594. Washington, DC: National Academy of Sciences, 1968: 3–12.
10. Benjamin SA, Angleton GM, Bishop L, et al. Hematopoietic neoplasms and related disorders in beagles irradiated during development. Radiat Res 1981;87:505–13.
11. Reif JS, Schweitzer DJ, Ferguson SW, et al. Canine neoplasia and exposure to uranium mill tailings in Mesa County, Colorado. In: Epidemiology applied to health physics; proceedings of the 16th midyear topical meeting, Health Physics Society, Albuquerque, NM, January 1983:461–9.
12. Hayes HM, Tarone RE, Kantor KP, et al. Case-control study of canine malignant lymphoma: positive association with dog owner's use of 2,4-dichlorophenoxyactic acid herbicides. J Natl Cancer Inst 1991;83:1226–31.
13. Leeper E, Wertheimer N, Savitz D, et al. Modification of the 1979 "Denver wire code" for different wire or plumbing types. Bioelectromagnetics 1991;12:315–18.
14. Mantel N, Haenszel W. Statistical aspects of the analysis of data from the retrospective study of disease. J Natl Cancer Inst 1959;22:719–48.
15. Miettinen OS. Estimability and estimation in case-referent studies. Am J Epidemiol 1976;103:226–35.
16. Mantel N. Chi-square tests with one degree of freedom: ex-

tensions of the Mantel-Haenszel procedure. J Am Stat Assoc 1963;58·690–700
17. Breslow NE, Day NE. Statistical methods in cancer research. Vol 1. The analysis of case-control studies. (IARC scientific publications no. 32). Lyon: International Agency for Research on Cancer, 1980.
18. Fulton JP, Cobb S, Preble L, et al. Electrical wiring configurations and chıldhood leukemia in Rhode Island. Am J Epidemiol 1980;111:292–6.
19. Wertheimer N, Leeper E. Re: "Electrical wiring configurations and childhood leukemia in Rhode Island." (Letter). Am J Epidemiol 1980;111:461–2.
20. Myers A, Clayden AD, Cartwright RA, et al. Childhood cancer and overhead power lines: a case-control study. Br J Cancer 1990;62:1008–14.
21. Savitz DA, Kaune WT. Childhood cancer in relation to a modified residential wire code. Envıron Health Perspect 1993; 101:76–80.
22. Barnes F, Wachtel H, Savitz D, et al. Use of wiring configuration and wiring codes for estimating externally generated electric and magnetic fields. Bioelectromagnetıcs 1989;10: 13–21.
23. Kaune WT, Stevens RG, Callahan NJ, et al. Residential magnetic and electric fields Bioelectromagnetics 1987;8.315–35.
24. Jones TL, Chih CH, Thompson DH, et al. Selectıon bias from differential residential mobility as an explanation for associations of wire code wıth chıldhood cancer. J Clin Epidemiol 1993;46:545–8.
25. Smith AH, Pearce NE, Callas PW. Case-control studies with other cancers as controls. Int J Epıdemiol 1988;17:298–306.
26. Pearce N, Checkoway H. Case-control studies using other diseases as controls: problems of excluding exposure-related dıseases. Am J Epidemiol 1988;127:851–6.
27. Glickman LT, Domanski LM, Maguire TG, et al. Mesothelioma in pet dogs associated with exposure of their owners to asbestos. Environ Res 1983;32:305–13.
28. Reif JS, Dunn K, Ogilvie GK, et al. Passive smoking and canine lung cancer risk. Am J Epidemiol 1992;135:234–9.