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Original Contributions

ELECTRICAL WIRING CONFIGURATIONS AND CHILDHOOD CANCER

NANCY WERTHEIMER[1] AND ED LEEPER

Wertheimer, N. (Dept. of Preventive Medicine, U. of Colorado Medical Center, Box C-245, Denver, CO 80262), and E. Leeper. Electrical wiring configurations and childhood cancer. *Am J Epidemiol* 109:273–284, 1979.

An excess of electrical wiring configurations suggestive of high current-flow was noted in Colorado in 1976–1977 near the homes of children who developed cancer, as compared to the homes of control children. The finding was strongest for children who had spent their entire lives at the same address, and it appeared to be dose-related. It did not seem to be an artifact of neighborhood, street congestion, social class, or family structure. The reason for the correlation is uncertain; possible effects of current in the water pipes or of AC magnetic fields are suggested.

electricity; electromagnetic fields; leukemia; neoplasms

Electrical power came into use many years before environmental impact studies were common, and today our domestic power lines are taken for granted and generally assumed to be harmless. However, this assumption has never been adequately tested. Low level harmful effects could be missed, yet they might be important for the population as a whole, since electric lines are so ubiquitous. In 1976–1977 we did a field study in the greater Denver area which suggested that, in fact, the homes of children who developed cancer were found unduly often near electric lines carrying high currents.

In our modern power delivery systems, high-tension wires carrying current at voltages up to several hundred kilovolts (kv) deliver power to distribution substations where the voltage is stepped down, resulting in proportionately higher current in the medium-voltage (usually 13 kv, wire-to-wire) primary lines. These latter radiate out from the substation to distribute power through a neighborhood. Then, at the local transformer, the voltage of the primaries is stepped down once more to produce the 240 volt current which is carried along the secondary wires to service drops which bring the power to the customer's house. The current flow will always be greatest in the wires directly issuing from the substation or the transformer. At these points the voltage has been stepped down and "transformed" into current. And it was particularly homes close to these transforming points that were over-represented among our cancer cases.

Because our findings appeared to relate to high current rather than voltage, we looked into the magnetic fields induced by current flow. Magnetic fields penetrate the human body (and buildings, etc.) readily. They are not easily shielded, but

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Abbreviations: AC, alternating current; HCC, high-current configuration; Hz, hertz; LCC, low-current configuration.

[1] Department of Preventive Medicine and Community Health, Box C-245, University of Colorado Medical Center, 4200 East Ninth Avenue, Denver, CO 80262. (Reprint requests to Dr. Wertheimer.)

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TABLE 1

Daytime measurements of 60 Hz magnetic fields (in RMS gauss) in Colorado in 1976–1977

	75 cm above ground, under wires					75 cm above ground over buried plumbing which serves:	
	Large primaries (N = 64)*	High tension (N = 22)*	Thin primaries (N = 51)*	First span† secondaries (N = 84)*	Second span† secondaries (N = 73)*	First span† homes (N = 160)*	Second span† homes (N = 104)*
Maximum measurements	.035	.020	.008	.005	.004	.013	.008
Median measurements	.007	.0033	.0022	.0017	.0009	.0015	.0010
% >.0030 gauss	73.4%	54.5%	35.3%	20.2%	6.8%	22.5%	10.4%

* N = no. of sites studied.

† First span secondaries are those nearest the transformer; second span wires are further "down-stream" from the transformer (see text). First- and second-span homes are homes near the respective types of secondaries.

they can be cancelled by balancing the currents that produce them. Such cancellation occurs in electric wires, where the return current tends to balance the supply current. However, the cancellation is imperfect because the wires are often separated in space and, more importantly, because some of the return current does not flow through the wires at all, but returns instead through the ground, and particularly through the plumbing system to which most urban electrical systems are grounded at each house.

This results in a locally imbalanced current, both in the distribution wires and in the plumbing. That imbalanced current produces a 60 hertz (Hz) magnetic field which, though small (table 1), is nonetheless orders of magnitude larger than the 60 Hz field found in nature (about 10^{-8} gauss (1)). The ground-current flows not only in the street plumbing, but also through the pipes in the house. Current which enters the plumbing at one house can flow through several homes before it returns to the distribution wires, because the plumbing provides a continuous, low-resistance path between houses.

The ground-current produces a magnetic field within the house (localized near the plumbing) which appears to be related roughly to the types of wiring configurations nearby (see table 1). This relationship between wires and plumbing is to be expected because, other things being equal, the greatest unbalanced current tends to occur where the total current in the wires is greatest, and the unbalanced portion of the current must detour through ground paths such as the nearby earth and plumbing.

A number of household appliances and power tools also produce magnetic fields, but in comparing the fields from appliances with those from power lines, it is important to note that most appliances present approximately a magnetic dipole source, with fields falling off roughly as the inverse cube of the distance, while a wire with unbalanced current will have a field falling off only as the inverse of the distance. For instance:

	1 cm	15 cm	1 m	3 m	30 m
Electrical drill	13 gauss	.12	.001	<.0001	<.0001
Electrical range (4 burners on high)	1 gauss	.04	.0015	<.0001	<.0001
Wire carrying 15 amperes	3 gauss	.2	.03	.01	.001

In the literature there are listings of 60 Hz magnetic fields produced by appliances which appear quite high. These should not be misinterpreted: They are apparently due to the use of measurements taken "as close as possible" to the appliance. Our measurements indicate that magnetic-field exposure to the whole body from normal use of household appliances rarely exceeds .001 to .002 gauss for any extended period, while the ambient fields in a house due to nearby distribution wires or plumbing may sometimes reach those levels, or more, for hours or days at a time. If magnetic-field exposure is responsible for our finding, it may be that, above some minimum threshold, duration of continuous exposure is more important than strength of exposure *per se*. There is some precedent for such a threshold effect in the literature on direct current (DC) magnetic fields (2).

Our field measurements showed that, on the average, those types of wires associated with cancer in our study exhibited high magnetic fields (compare tables 1 and 3). However, the readings varied considerably over time; and because our observations were all made in good weather and during work-day hours when domestic current is minimal, because current-flow had most probably altered since the time of our subjects' residency, and because it was rarely feasible to go close to the house to take a measurement, no attempt was made to take systematic measurements at our study homes. Rather this study is based on the *potential* current flow suggested by different wiring configurations (nearness and size of wires, closeness to origin of current, etc.).

Experimental work on physiologic effects of low-level, extremely low frequency magnetic fields is limited. It has been recently reviewed (3). Among the positive reports are decreased mitosis in slime molds (4), decreased growth of seedlings (5) and chicks (6), decreased *in vitro* growth of embryonic tissue cells (7), and a number of behavioral and physiologic changes in rats (8). All these results are for fields considerably higher (.5–30 gauss) than the 60 Hz fields generally found near power lines; however, the findings reported often appear to be unrelated to dose over the range studied. Prolonged exposure to the .001–.1 gauss range most pertinent to wiring effects has not been explored experimentally.

Two studies suggest that a relatively strong AC (alternating current) field may interfere with growth of implanted tumors in animals (9, 10) except where the tumor tissue is exposed to the field *before* implantation. In this latter condition, tumor "takes" were increased (9).

To explore occupational exposure to AC magnetic fields, we analyzed data from a USPH publication on occupation by cause of death (11). All those occupational categories which seemed likely to include men frequently exposed to AC magnetic fields were grouped together and found to have, as a group, a cancer rate significantly higher than the total population. The "exposed" categories included: power station operators; stationary engineers; linemen and servicemen, telephone, telegraph and power; motor-men, street, subway and elevated railway; electricians; and welders and flame cutters. The standard mortality ratio for cancer for these categories combined was 115, a significant increase over the ratio of 100 for all occupations ($\chi^2 = 24.5, p < .0001$). For other "natural causes" of death this same group showed a standard mortality ratio of 102 ($\chi^2 = 1.8$, not significant). While this crude analysis in itself proves nothing, it underlines the fact that the harmlessness of AC magnetic fields is still unproven.

METHODS

Our cases consisted of persons dying of cancer in Colorado before age 19 in the years 1950–1973, who also had a Colorado birth certificate. Only subjects with addresses occupied from 1946–1973 in the greater Denver area were used. Controls for these cases consisted of next Denver-area birth certificates, chosen both from the files organized by birth-month and county (*file 1 controls*), and from the alphabetical search-listings, which list all Colorado births alphabetically within several wide spans of years: 1939–1958, 1959–1969, and 1970–1974. These latter were called *file 2 controls*. If the next birth certificate was that of a sibling it was skipped.

Birth addresses were those listed on the birth certificates. "Death" addresses were obtained for both cases and controls by searching for parents in city directories for the two years just prior to diagnosis of the case. For cases who could not be traced, the address on the death certificate was used. For controls, if the *file 1 control* could not be traced, the *file 2 control* with most similar birth date who could be traced was used. There were no significant differences in the proportion of "high-current configurations" (HCC's as defined below) shown by the *file 1 controls* used (21 per cent HCC), the *file 2 controls* used (23 per cent HCC) and the unused extra controls (25 per cent HCC), so it seems unlikely that our method of selecting controls biased our findings.

In all, 344 cases met our criteria. Thirty-nine of these were born before 1946, and 33 had a birth address which was lost because it had been demolished or was not adequately specified. Only death addresses were analyzed for these 72 cases and their respective controls. Similarly, 16 cases had no usable death address, so only birth addresses were used for these cases and their controls. Table 2 gives a summary of how many persons and how many addresses were available for cases and controls.

The procedure was simply to visit the birth and "death" addresses of each case and each control, and to draw a small map of the electrical wires and transformers in the vicinity. Primary (13 kv) wires were categorized as either "large-gauge" (built

TABLE 2

Distribution of persons and addresses available for analysis, for cases and controls, in a study of electrical wiring configurations and childhood cancer in Colorado in 1976–1977

Residential status	Cases		Controls	
	Persons*	Addresses*	Persons	Addresses
Stable	109	109	128	128
Moved, birth and death addresses available	147	294	128	256
Only birth address	16	16	16	16
Only death address	72	72	72	72
Totals	344	491	344	472

* Tables 3, 4, and 9 present data on total addresses, tables 5, 6, 7, 8, and 10 present data on total persons. Tables presenting data on persons are generally broken into total persons with an available birth address ($N = 272$) and totals with an available death address ($N = 328$).

to carry high currents) or "thin" depending on whether they were clearly larger than the secondary wires. Distances were measured from the part of the house nearest the wires to the wires, with a rollatape.

Three types of homes, because of their proximity to high-current wires, were considered to have "high-current configurations" (HCC's): 1) homes less than 40 meters from large-gauge primaries or an array of six or more thin primaries; 2) homes less than 20 meters from an array of 3–5 thin primaries or from high-tension (50–230 kv) wires; and 3) homes less than 15 meters from "first span" secondary (240 volt) wires. *First span secondaries* were defined as those secondaries which issued directly from the transformer and had not yet lost any current through a service drop occurring beyond the transformer pole. The span of secondary wires separated from any transformer by at least one intervening service drop (ignoring those drops directly attached to the transformer pole) were called *second span secondaries*. First span wires will have more current running through them than second span wires because the first span must carry current for all the drops that mark its distal end *plus* whatever current the second span requires.

All other configurations were considered "low-current configurations" (LCC's). In addition, where first span wires could be seen to be carrying current to no more than two single family homes, on the average (on both sides of the block), those wires were called *short first span* wires and, because they carried current for so few homes, they were always considered LCC's, regardless of distance. Houses situated beyond the pole at the end of a secondary line ("end poles" in tables 3 and 4) were considered the extreme example of LCC homes, because they had no distribution wires at all running past them.

Since the Denver area has been growing fast, many new primary wires have been installed to accommodate increased power demands. Many of these new installations are of a style easily distinguished from older wires. For addresses occupied before 1956 (20 years prior to our field work) we noted that only 59 per cent of the primary wires found near our study homes were of the "old fashioned" types which had been in use at the time of our subjects' occupancy. (Actually 71 per cent of the primary wires observed near pre-1956 case addresses were "old fashioned," but only 49 per cent of the wires near pre-1956 control addresses were of the older types that could have been in use in those early years.) Where the more modern wiring was observed, we could not tell whether it represented new installations or replacement wiring, but we did know that it could not have been there in its present form in the pre-1956 years. Therefore, we decided to treat all primary wires seen near homes occupied before 1956 as unreliable, and to code such homes strictly according to their more stable secondary-wire configurations.

This adjustment did not critically affect our findings. Proximity to primary wires was most strongly associated with cancer for recent addresses, and the association (as expected) was weaker in the older data. But the association was still significant when all years were considered and no adjustments made: For birth addresses, 31 per cent of the 272 cases and 22 per cent of the 272 controls had homes near (unadjusted) primaries, a difference significant beyond the .025 level by Chi-square. For death addresses the figures were 29 per cent of 328 cases and 19 per cent of 328 controls, significant beyond the .01 level.

Results

General configurations. Table 3 shows how many cancer and control homes exhibited the various wiring configurations. It can be seen that the most striking difference between cases and controls was found for subjects who had only one address from birth to death. This might be because, for subjects who moved, the effects of configurations at one address were diluted by effects of configurations at other addresses.

Table 4 indicates that the greater the exposure to current expected from a given wiring configuration, the greater the excess of cancer found in homes where that configuration was observed.

Type of cancer. The breakdown according to type of cancer (table 5) shows a fairly similar excess of HCC's in cancer cases for all categories but one, the death addresses of cases with "other tumors." Such a wide association with different types of cancer is not characteristic of known carcinogens such as ionizing radiation; thus the broad association observed here suggests that the HCC-cancer relationship may not be a causal one. The most likely alternatives are that it is due to some artifact, or that it reflects some effect of HCC's on the body's general ability to resist cancer.

Onset age. As table 6 shows, the HCC-cancer relationship was observed in both young and older subjects. The fact that the relationship held for the birth as well as the death addresses of older subjects would seem to suggest that the effects of HCC exposure can be long delayed. However, a closer look at the data showed that

TABLE 3

Wiring configurations at the homes of cancer cases and controls, Colorado, 1976–1977

Type of configuration*	Stable residence:		Moved residence:			
			Birth address		Death address	
	Case	Control	Case	Control	Case	Control
Substation <150 m†	2	0	2	0	2	0
Large primaries <40 m	14	6	14	13	38	17
High tension <20 m	0	0	0	1	1	0
Thin primaries <20 m	13	10	11	4	17	11
1st span secondaries <15 m	19	10	26	11	23	20
Total HCC's	48	26	53	29	81	48
1st span secondaries >15 m	33	43	53	57	66	51
"Short" first span wires	6	11	9	4	11	19
Second span secondaries	20	33	40	40	51	66
End poles	2	15	8	14	10	16
Total LCC's	61	102	110	115	138	152
(% HCC)	(44.0)	(20.3)	(32.5)	(20.1)	(37.0)	(24.0)
	$\chi^2 = 14.4$		$\chi^2 = 5.4$		$\chi^2 = 7.6$	
	$p < .001$		$p = .02$		$p < .01$	

† All six cases within 150 m of a substation were also less than 40 m from large primaries.
* HCC = high-current configuration; LCC = low-current configuration.

TABLE 4

Cancer related to the amount of current expected from different wiring configurations, Colorado, 1976–1977

Wiring configuration	Expected current	Total addresses:		
		Case	Control	% cases
Substation	Very high	6	0	100.0
Other HCC	High	176	103	63.1
LCC except end poles	Low	289	324	47.1
End poles	Very low	20	45	30.8

TABLE 5

Wiring configurations and type of cancer, Colorado, 1976–1977

Residence	Type of wiring configuration*	Leukemia		Lymphoma		Nervous system tumors		Other	
		Case	Control	Case	Control	Case	Control	Case	Control
Birth address	HCC	52	29	10	5	22	12	17	9
	LCC	84	107	21	26	35	45	31	39
	(% HCC)	(38.2)	(21.3)	(32.3)	(16.1)	(38.6)	(21.1)	(35.4)	(18.7)
Death address	HCC	63	29	18	11	30	17	18	17
	LCC	92	126	26	33	36	49	45	46
	(% HCC)	(40.6)	(18.7)	(40.9)	(25.0)	(45.5)	(25.8)	(28.6)	(27.0)

* HCC = high-current configuration; LCC = low-current configuration.

23 (66 per cent) of the 35 older cases born at HCC's were also living at a HCC (usually the same address) within two years of their cancer onset. Only three (20 per cent) of the 15 older controls born at HCC's were living at a HCC within two years of the "death" date. Thus the HCC-cancer relationship observed in the birth addresses of older subjects can be largely attributed to a HCC residence near the time of cancer onset, and there is no need to posit a long-delayed effect of HCC's.

Urban-suburban differences. Since cancer may show a different incidence in urban and non-urban areas, it seemed important to rule out the possibility that a difference in urbanization between cases and controls was the significant variable in this study, and simply carried the HCC differences with it, spuriously. This seemed unlikely, intuitively, because the field work was done one neighborhood at a time, and on none of the 22 days of field work did the individual day's results fail to show a preponderance of HCC's in the case addresses.

A more formal survey shows that, although there was a slight excess of suburban addresses in the controls, it was not statistically significant. Furthermore, the cases showed more HCC's than the controls independently in three areas: in old Denver, in the more recently developed Denver areas (as estimated from a planning department publication (12)), and in the Denver suburbs (see table 7).

Socioeconomic class. The literature reports an excess of leukemia in families of higher socioeconomic class (13). Our data, dealing with all types of childhood cancer, show only an insignificant trend in this direction. It seemed possible that our method of choosing controls might have biased our control group against lower-class controls, since only controls who could be traced in directories were used. However, a check on the discarded controls showed that upper and lower class controls were discarded equally often, while Class III controls were somewhat disproportionately retained. There was no significant difference in the per cent of discarded and retained controls showing a HCC and, as table 8 shows, the association between HCC's and cancer was observed within each social-class group. It therefore seems unlikely that some spurious relationship to social class explains our findings.

Family pattern. The literature reports an excess of first siblings and older mothers among children with leukemia (14). In our total sample of childhood cancer cases, a trend towards both more first siblings and older mothers was noted, but neither was statistically significant. Furthermore, the HCC-cancer relationship holds to approximately the same degree within each maternal-age and sibling-order category tested, so we see no clue in these variables as to why the relationship between HCC's and cancer should exist.

Traffic congestion. A recent report (15) suggests that cancer may occur unduly often near heavy-traffic routes. Our data did show a mild excess of case-addresses near such routes; case-addresses were more likely than control-addresses to be found within 40 meters of streets having a daily traffic count of 5000 vehicles or more on the 1960 Department of Highways traffic map. However, once again, a significant excess of HCC's in cancer cases was found independently for addresses on heavy-traffic routes and for other addresses. (For heavy-traffic routes, 53 per cent of 74 case-addresses showed HCC's against 30 per cent of 48 control-addresses; for other locations, 35 per cent

TABLE 6

*Wiring configurations and cancer onset age, Colorado, 1976–1977**

Residence	Type of wiring configuration†	Cancer onset 0–5 years		Onset 6–18 years	
		Case	Control	Case	Control
Birth address	HCC	66	40	35	15
	LCC	103	129	68	88
	(% HCC)	(39.1)	(23.7)	(34.0)	(14.6)
Death address	HCC	68	37	61	37
	LCC	105	136	94	118
	(% HCC)	(39.3)	(21.4)	(39.4)	(23.9)

* Case-control differences are significant by Chi-square ($p < .01$) for each category in the table.
† HCC = high-current configuration; LCC = low-current configuration.

TABLE 7

*Wiring configurations in different neighborhoods of cancer cases and controls in Colorado in 1976–1977**

Residence	Type of wiring configuration†	Old Denver		Newer Denver		Suburban	
		Case	Control	Case	Control	Case	Control
Birth address	HCC	42	26	27	9	32	20
	LCC	77	91	40	44	54	82
	(% HCC)	(35.2)	(22.2)	(40.3)	(17.0)	(37.2)	(19.6)
Death address	HCC	49	24	35	19	45	31
	LCC	62	77	49	55	88	122
	(% HCC)	(44.1)	(23.8)	(41.7)	(25.7)	(33.8)	(20.3)

* Case-control differences are significant by χ^2 ($p < .05$ or better) for each category in the table.
† HCC = high-current configuration; LCC = low-current configuration.

TABLE 8

Father's occupational class at subject's birth, related to wiring configurations at birth residences of cancer cases and controls, Colorado, 1976–1977*

Type of wiring configuration†	Classes I and II		Class III		Classes IV and V	
	Case	Control	Case	Control	Case	Control
HCC	19	9	49	30	33	16
LCC	34	41	98	111	39	65
(% HCC)	(35.8)	(18.0)	(33.3)	(21.3)	(45.8)	(19.8)
	$\chi^2 = 3.2$		$\chi^2 = 4.7$		$\chi^2 = 10.8$	
	$p < .10$		$p < .05$		$p \cong .001$	

* Class categories follow the schema provided in "Mortality by Occupation Level and Cause of Death," Vital Statistics Special Reports 53, #5, 1963, and are as follows: Class I: Professional. Class II: Technical, Administrative and Managerial. Class III: Clerical, Sales, and Skilled Workers. Class IV: Semi-skilled Workers. Class V: Laborers.

† HCC = high-current configuration; LCC = low-current configuration.

TABLE 9

Increase of cancer cases within 40 meters of heavy-traffic routes, as related to the presence or absence of nearby primaries, Colorado, 1976–1977*

Type of subject	Near primary wires		Not near primaries	
	Traffic routes	Other locations	Traffic routes	Other locations
Cases	32	84	42	333
Controls	9	53	39	371
(% cases)	(78.0)	(61.3)	(51.9)	(47.3)
	$\chi^2 = 3.3$		$\chi^2 = 0.4$	
	$.05 < p < .10$		Not significant	

* "Nearby" primaries here means that the primaries were near enough to the house to qualify it as a high-current configuration (HCC).

of 417 case-addresses showed HCC's against 21 per cent of 424 control-addresses).

In fact, the excess cancer we found on heavy-traffic routes seems to be related to the frequent presence on such routes of primary wires carrying especially high currents. Table 9 shows that the excess of cancer cases on high-traffic routes occurred to a significant extent *only* where primary wires were nearby.

Sex distribution. Many cancers, including leukemia, occur more frequently in males than females. This is reflected in our data where 57 per cent of our cases were males, as compared to 49 per cent of the controls. The excess of HCC's among cases was significant for both males and females when the sexes were analyzed separately, but the trend was stronger in the males; 51 per cent of the 197 male cases had a HCC at their birth- or death-address, or both, while 45 per cent of the 147 female cases had such an address. This compares with only 28 per cent of the 168 control males and also 28 per cent of the 176 control females.

It is interesting that significant male excess among our cancer cases appeared to be confined to two categories: 1) cases whose birth address had a lower current configuration than the death address, and 2) cases with stable address who developed cancer after at least one year of postnatal life at a residence situated near primary wires (table 10).

Because these two categories were chosen from a number of ways we might have categorized the data, they must remain suspect until a replication confirms or

TABLE 10

Sex distribution of cancer cases in a study of electrical wiring configurations and childhood cancer in Colorado in 1976–1977

Type of address	Males	Females	% male	Significance*
Birth address had lower current configuration than death address	28	14	66.7	$\chi^2 = 4.0, p < .05$
Stable residence at HCC† involving primary wires	22	4	84.6	$\chi^2 = 11.1, p < .001$
Other cases with any HCC address	56	48	53.8	$\chi^2 = 0.5$, not significant
Other cases with no HCC address	91	81	52.9	$\chi^2 = 0.5$, not significant

* An expected value of 50 per cent male was used to calculate the chi-squares.

† HCC = high-current configuration.

disputes them. However, we chose these categories for a reason: We hypothesized that males might be excessively susceptible to HCC's at all ages, including prenatally. (It is of interest here that male rats appear especially susceptible to experimental magnetic fields (8, p. 182) (16), as do embryos (17).) If males are more susceptible, they might frequently be aborted when pregnancy occurs at a HCC, but pregnancy at a LCC would allow the most susceptible males to be born and then to develop cancer later when exposed to a situation with higher current nearby. This hypothesis is consistent with the male excess in category 1 above.

Category 2 is presumed to provide a potentially similar situation: Where primary wires are found running near a house (in 1976), it is always possible that these wires were first installed or were "beefed up" at some time *after* the subject's birth. Or if they were present all along, the current they carry may sometimes have increased with time. If any of these things happens, the postnatal current flow near the house will be increased over the prenatal flow, even without a change in residence. Should this happen, the susceptible male who escaped abortion during pregnancy might develop cancer, and this would explain the male excess in category 2.

Substations. Power carried at higher voltage is stepped down to produce increased current at two points in our electrical distribution system: at the distribution substation, and again at the neighborhood transformers. As indicated, cancer cases were found in excess close to the "first span" wires issuing from the transformers. An even stronger trend was found for substations.

None of the 702 control addresses visited (including our unused extra controls) was within 150 meters of a substation. This is to be expected since probably less than one home in 1000 in the Denver area is that near a substation. What is surprising is that six of 491 case addresses were found within 150 meters of a substation and, in each case, less than 40 meters from the large primary wires issuing from that substation. These six are shown in table 3. Each cancer case had lived at the substation address within three years or less of his illness. Although these numbers are small, they are striking.

Blind studies. It should be noted that our Denver-area study, being exploratory, was not done blind. This could lead to error, although our observations were reasonably unambiguous. To check just how reliable our coding was, an assistant observed and coded 70 case and 70 control addresses randomly chosen from those previously coded by the principal investigator. The assistant did not know the case-control status of the addresses she coded. Her coding agreed with ours in 128 (91 per cent) of the 140 instances. In five of the 12 instances of disagreement, the assistant's judgment favored the hypothesis of a HCC-cancer correlation, while ours did not. In seven instances, the reverse was true.

Also, a blind study was done (for birth addresses only) in Colorado Springs and Pueblo. This study showed the same correlation as the Denver study, similar in degree but less significant due to the smaller numbers; 32 per cent of the 65 cases and 18 per cent of the 65 controls showed HCC's. The correlation was strongest for cases with onset before six years of age, possibly because many of the older cases had been gone from their birth addresses for many years before their cancer onset.

Discussion

It is not clear *how* residence near a HCC might affect the development of cancer, but several possibilities should be considered:

1) Some association of both cancer and HCC's with a third factor may spuriously account for our correlation. Although we found no indication of such a third factor in our analyses of social class, neighborhood, congested streets, or family make-up, the possibilities have not been exhausted.

2) The magnetic fields produced by wire currents may somehow directly "cause" cancer. There is, however, no independent evidence or theoretical understanding which seems to support this possibility. The evidence concerning mutagenic effects of extremely low frequency magnetic fields, for instance, is ambiguous, but probably negative (18).

3) Carcinogenic activity may be associated with some *indirect* effect of the HCC's. For example, fields around power lines might change the distribution of some ambient environmental carcinogen, such as particles which emit ionizing radiation. (However, the fields near domestic wires are too weak to make this seem probable.) Or the increased current flowing in the plumbing might locally affect the drinking water. (There is often a small amount of lead in copper water pipes, for instance, due to imperfect soldering. And lead in the water supply is correlated with cancer, at least geographically (19). However, it is not clear that AC current in pipes could affect this small amount of lead enough to make a difference.)

4) AC magnetic fields might affect the development of cancer indirectly, through some effect on physiologic processes. It is conceivable, for instance, that contact-inhibition of cellular growth, or the basic immune reaction of recognizing "self" from "not self," involves electrical potentials occurring at cell surfaces. Against an electromagnetic background different from that provided during evolution, any such cell mechanism might be altered.

Whatever the basis for our observed correlation, it should be emphasized that, although the risk of cancer appears to be increased for children living near HCC's, it is rarely increased by a factor of more than two or three. Therefore, if in the general population one child in 1000 is likely to get cancer before age 19, no more than two or three in 1000 living near a HCC would be expected to get it. The practical significance of the correlation, if any, lies in the high prevalence of HCC's, not in any very high risk posed by most HCC's.

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