Environmental Health Perspectives
Vol. 62, pp. 297-300, 1985

Mortality in Workers Exposed to Electromagnetic Fields

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In an occupational mortality analysis of 486,000 adult male death records filed in Washington State in the years 1950–1982, leukemia and the non-Hodgkin's lymphomas show increased proportionate mortality ratios (PMRs) in workers employed in occupations with intuitive exposures to electromagnetic fields. Nine occupations of 219 were considered to have electric or magnetic field exposures. These were: electrical and electronic technicians, radio and telegraph operators, radio and television repairmen, telephone and power linemen, power station operators, welders, aluminum reduction workers, motion picture projectionists and electricians. There were 12,714 total deaths in these occupations. Eight of the nine occupations had PMR increases for leukemia [International Classification of Diseases (ICD), seventh revision 204] and seven of the nine occupations had PMR increases for the other lymphoma category (7th ICD 200.2, 202). The highest PMRs were seen for acute leukemia: (67 deaths observed, 41 deaths expected; PMR 162), and in the other lymphomas (51 deaths observed, 31 deaths expected; PMR 164). No increase in mortality was seen for Hodgkin's disease or multiple myeloma.

These findings offer some support for the hypothesis that electric and magnetic fields may be carcinogenic.

In Washington State, all male death records for the years 1950–1982 have been coded to occupation. Analyses of the 1950–1971 data and of the 1950–1979 data have been published (*1,2*). In the 1950–1979 data set, men whose occupations were associated with electric or magnetic fields had more deaths due to leukemia than would be expected (*3*). This association has been supported in data from a Los Angeles County Cancer Registry (*4*), in Vital Statistics for England and Wales (*5*), and in a British Cancer Registry (*6*). Since three more years of data are now available, I examined the patterns of mortality in electrical workers in greater detail.

Methods

All deaths of Washington State resident men, age 20 years or older, from 1950 to 1982, were coded to occupation. This file contains 486,000 deaths. Proportionate mortality ratios (PMRs), standardized by age and year of deaths, were calculated for 158 cause-of-death groups in each of 219 occupational classes. For this analysis, the following occupations were considered to have electric or magnetic field exposures: electrical and electronic technicians, radio and telegraph operators, electricians, linemen (power and telephone), television and radio repairmen, power station operators, aluminum workers, welders and flame-cutters, and motion picture projectionists. Electrical engineers were not included, because their electrical exposures are infrequent and because of potential social class confounding of the mortality ratios. Streetcar and subway motormen were not included because of too few deaths in recent years (11 total deaths since 1970).

Aluminum potroom workers are exposed to strong magnetic fields created by the high amperage direct current (75,000 A) used in the aluminum reduction process. They are also exposed to polycyclic organic matter generated when the binder in the carbon electrodes is burned.

The welder group includes flame-cutters and gas welders who have no electrical exposures. Arc welders work near step-up transformers, but are also exposed to ozone, oxides of nitrogen and metal fumes. The motion-picture projectionists also work near step-up transformers but, like aluminum workers, have exposures to burning carbon electrodes and polycyclic organic matter.

Those electricians engaged in new house wiring have minimal electric field exposures; electricians who work for electric utilities may have high field exposures.

The workers in the other occupations are exposed to electromagnetic fields associated with alternating current flowing in wires and powerlines. The power station operators work in hydroelectric plants along the Columbia River. They are also exposed to ozone, especially when working in the turbine housings.

Results and Discussion

Table 1 presents observed and expected deaths and PMRs for those causes with significant ($p < 0.05$) ex-

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Table 1. Mortality in workers occupationally exposed to electromagnetic fields Washington State 1950–1982, white males, age 20+; all causes with statistically significant differences between observed and expected deaths.[a]

Cause of death	7th ICD[b]	Deaths		
		Observed	Expected	PMR[c]
Tuberculosis	001–019	28	48	59†
All malignant neoplasms	140–205	2,649	2,501	106†
Malignant neoplasm:				
Pancreas	157	174	149	117*
Bronchus, trachea and lung	162	789	694	114†
Brain	193.0	101	82	123*
Other lymphomas	200.2,202	51	31	164†
Leukemia	204	146	108	136†
Acute leukemia	204.3	67	41	162†
Neoplasm of unspecified nature	230–239	17	11	162†
Diabetes mellitus	260	147	179	82*
Cerebral hemorrhage	331,334	632	685	92*
Other disease of heart	430–434	336	379	89*
Bronchitis with emphysema	502.0	43	30	145*
Other chronic interstitial pneumonia	525	38	27	143*
Other diseases of lung	527	412	372	111*
Ulcer of stomach	540	60	42	142†
Cirrhosis of liver w/o alcoholism	581.0	139	165	84*
Aircraft accidents	860–866	27	41	65*
Other falls from one level to another	902	58	42	138*
Electrocution	914	105	15	708*

[a] Electrical and electronic technicians, radio and telegraph operators, electricians, power and telephone linemen, radio and television repairmen, motion picture projectionists, aluminum workers, power station operators, welders, and flame-cutters.
[b] International Classifications of Diseases, seventh revision.
[c] PMR = proportionate mortality ratio (observed/expected × 100).
*$p<0.05$.
†$p<0.01$.

Table 2. Mortality in workers occupationally exposed to electromagnetic fields, Washington State, 1950–1982, white males, age 20+, selected cancers.

Occupation	Cancer of pancreas, ICD 157			Cancer of lung, ICD 162			Cancer of brain, ICD 193.0		
	Observed	Expected	PMR[a]	Observed	Expected	PMR[a]	Observed	Expected	PMR[a]
Electromagnetic field exposure									
Electrical and electronic technicians	9	6.3	143	32	35.2	91	7	5.2	134
Radio and telegraph operators	8	7.1	112	20	25.0	80	1	2.6	38
Power and telephone linemen	18	13.8	130	74	61.7	120	6	7.8	77
Radio and television repairmen	4	5.1	79	23	26.4	87	2	3.4	59
Power station operators	3	5.1	59	21	22.6	93	3	2.3	130
Subtotal	42	37.4	112	170	170.9	100	19	21.3	89
Electromagnetic field and other exposure									
Electricians	65	61.3	106	294	272.2	108	46	29.7	155†
Motion picture projectionists	7	2.7	260†	8	10.4	77	2	1.1	188
Aluminum workers	33	18.3	180†	126	99.2	127†	15	10.9	137
Welders and flamecutters	27	29.0	93	191	141.5	135	19	18.8	101
Subtotal	132	111.3	119	619	523.3	118	82	60.5	136
Total	174	148.7	117*	789	694.2	114†	101	81.8	123*

[a] PMR = proportionate mortality ration (observed/expected × 100). Statistical testing was done only on observed values of six or greater.
*$p<0.05$.
†$p<0.01$.

cesses or deficits of deaths in the grouped electrical workers occupations. Since there are 120 separate causes of death for which PMRs are calculated at the $p < 0.05$ level, ($0.05 \times 120 = 6.0$) six causes of death would be expected to show significantly increased or decreased PMRs by chance alone. Actually, 19 causes of deaths had PMRs of $p < 0.05$. Six had lowered PMRs and 13 had elevated PMRs.

Deficits are seen for tuberculosis, diabetes mellitus, cerebral hemorrhage, other diseases of the heart, cir-

Table 3. Mortality in workers occupationally exposed to electromagnetic fields Washington State, 1950–1982, white males, age 20+, cancers of lymphatic and hematopoietic tissues.

Cause of death	7th ICD	Deaths		
		Observed	Expected	PMR[a]
All lymphatic and hematopoietic cancers	200–205	317	257	123†
Reticulum-cell sarcoma	200.0	12	15	78
Lymphosarcoma	200.1	41	31	130
Hodgkin's disease	201	38	33	114
Other lymphomas	200.2,202	51	31	164†
Multiple myeloma	203	29	37	78
All leukemias	204	146	108	136†
Lymphatic leukemia	204.0	36	29	126
Myeloid leukemia	204.1	29	23	126
Monocytic leukemia	204.2	6	6	104
Acute leukemia	204.3	67	41	162†
Unspecified leukemia	204.4	8	9	90

[a] PMR = proportionate mortality ratio (observed/expected × 100).
*$p<0.05$.
†$p<0.01$.

Table 4. Mortality in workers occupationally exposed to electromagnetic fields, Washington State, 1950–1982, white males, age 20+, selected cancers of lymphatic and hematopoietic tissues.[a]

Occupation	All lymphatic and hematopoietic, ICD 200–205			Lymphosarcoma, ICD 200.1			Other lymphomas, ICD 200.2, 202			Leukemia, ICD 204			Acute leukemia, ICD 204.3		
	Obs	Exp	PMR	Obs	Exp	PMR	Obs	Exp	PMR	Obs	Exp	PMR	Obs	Exp	PMR
Electromagnetic field exposure															
Electrical and electronic technicians	19	13.3	143	2	1.7	118	3	1.9	161	8	5.1	158	3	2.4	124
Radio and telegraph operators	15	10.9	137	1	1.4	73	4	1.2	342	5	4.9	102	3	1.4	212
Power and telephone linemen	31	25.2	123	5	3.0	168	5	2.8	177	17	10.8	158	7	3.9	179
Radio and television repairmen	12	9.4	127	1	1.1	90	1	1.2	86	7	4.0	176	6	1.7	344†
Power station operators	16	8.2	195†	3	1.0	297	3	1.0	300	8	3.5	226†	3	1.3	238
Subtotal	93	67.0	139†	12	8.2	146	16	8.1	197†	45	28.3	159†	22	10.7	206†
Electromagnetic field and other exposure															
Electricians	112	100.0	112	14	12.2	115	14	12.2	115	56	42.7	131*	25	15.6	160
Motion picture projectionists	5	4.1	122	1	0.4	250	0	0.3	0	4	1.8	218	1	.4	250
Aluminum workers	50	32.1	156†	3	3.7	82	11	4.2	260†	22	13.4	164	13	5.6	233†
Welders and flame-cutters	57	53.3	107	11	7.0	157	10	6.3	158	19	21.3	89	6	9.0	67
Subtotal	224	189.5	118	29	23.3	124	35	23.0	152†	101	79.2	128†	45	30.6	147†
Total	317	256.5	124†	41	31.5	130	51	31.1	164†	146	107.5	136†	67	41.3	162†

[a] Obs = observed deaths; EXP = expected deaths; PMR = proportionate mortality ratio (observed/expected × 100).
*$p<0.05$.
†$p<0.01$.

rhosis of the liver, and aircraft accidents. Excess deaths are seen due to all malignant neoplasms, malignant neoplasms of pancreas, lung, and brain, the other lymphomas, all leukemias, acute leukemia, neoplasms of unspecified nature, bronchitis with emphysema, chronic interstitial pneumonia, other diseases of lung, ulcer of the stomach, falls from one level to another, and accidental electrocution. Sixteen of 17 deaths due to neoplasms of unspecified nature were brain tumors, so this excess may be related to the malignant brain tumor excess. The accidental electrocution excess is limited to linemen (77 deaths observed, 2 expected) and to electricians (20 deaths observed, 4 expected). The excess of deaths due to falls from one level to another is seen only in linemen (24 deaths observed, 5 expected). The excess of deaths due to chronic pulmonary diseases [7th revision, International Classification of Diseases (ICD) Code 502.0 and 525] is seen primarily in those occupations with fume and dust exposures. Bronchitis with emphysema (7th ICD, 502.0) has excess mortality in welders (14 deaths observed, 6 expected) and in electricians (20 deaths observed, 13 expected). Chronic interstitial pneumonia deaths are in excess in welders (9 deaths observed, 5 expected) and aluminum workers (6

deaths observed, 3 expected). Deaths due to stomach ulcers show a slight excess mortality in these workers without any obvious occupational explanation.

Table 2 separates the nine occupations into two groups, one with electromagnetic field exposures only, and one with field exposure plus other occupational exposures. Pancreatic cancer shows a similar PMR in both groups while cancers of brain and lung show lowered PMRs in the electromagnetic field (only) exposure group. The lung, pancreas, kidney, and brain cancer excess is usually greatest in those occupations which have inhalation exposures in addition to electromagnetic field exposures. This suggests that field exposures may not play a role in the etiology of these cancers.

Table 3 shows observed and expected deaths and PMRs for the lymphatic and hematopoietic cancers. Reticulum-cell sarcoma and multiple myeloma show lowered PMRs, while all lymphatic and hematopoietic cancers, the other lymphomas, all leukemias, and the acute leukemias have significantly elevated PMRs ($p < 0.01$). Hodgkin's disease shows a slight but nonsignificant PMR increase with four of nine occupations having a PMR > 100. Only one of the nine occupation groups shows a PMR increase for multiple myeloma (aluminum workers: 8 observed, 5 expected, PMR 167). Similarly, based on small numbers of deaths, only two of nine occupation groups (power station operators and welders) show PMR increases due to reticulum-cell sarcoma.

Table 4 shows mortality by occupation due to lymphosarcoma, the other lymphomas, all leukemias, and acute leukemia. Some misclassification is possible among the reticulosarcoma, lymposarcoma, and other lymphoma categories. If the deaths in these cause groups are added, workers in these nine occupational groups have 104 deaths observed to 78 expected (PMR 133; $p < 0.01$). The highest PMRs are seen in the acute leukemia (162), and other lymphoma (164) categories. The PMRs are slightly higher in those occupations with electromagnetic field exposures only.

There is nothing in the available occupational literature which indicates that nonionizing radiation is a human carcinogen. There are conflicting reports relating residential electrical wiring configurations to cancer mortality (*7–9*). Occupational exposures to electric fields are much higher than those received by virtue of residence.

Weak electromagnetic fields can alter human reaction time (*10*) and circadian rhythm (*11*). Nonionizing radiation has been shown to cause endocrine (*12*), neurologic (*13*), and immunologic (*14*) changes in animals. Weak oscillating electric fields have been shown to affect calcium binding to cerebral tissue (*15*), and weak pulsed-magnetic fields have been shown to be teratogenic for the developing chicken (*16*). In most cases, these effects do not show the usual dose-response relationships. Rather, "windows" of effect of both frequency, power and wave form are seen. There are no systematic studies of the carcinogenicity of electromagnetic fields in animals.

Summary

Leukemia and non-Hodgkin's lymphomas show increased proportionate mortality ratios in men employed in occupations with intuitive exposures to electric and magnetic fields in Washington State.

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