A mortality study of electrical utility workers in Québec

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Abstract

***Objectives*—The objective of this study was to investigate the mortality of electrical utility workers exposed to electric and magnetic fields.**

***Methods*—A historical cohort mortality study was carried out on 21 744 workers who were employed in an electrical company in the province of Québec between 1970 and 1988. The last job held by each study subject was coded. A job exposure matrix (JEM) was used to estimate the exposure to 60 Hz electric and magnetic fields, and pulsed electromagnetic fields (as recorded by the PEMF (POSITRON) meter) in this job. Standardised mortality ratios (SMRs) were calculated relative to Québec men. Because the exposure was exclusively among blue collar workers, the remainder of the analyses by exposure were restricted to them. Rate ratios (RRs) in the exposed groups relative to the background groups were estimated with Poisson regression. There were 1582 deaths by the end of follow up.**

***Results*—SMRs were almost all below one and never substantially increased, although there were a few increased rate ratios (RRs). There was a significant RR of 2·00 (95% confidence interval (95% CI) 1·37–2·93) for deaths caused by accidents and violence in workers exposed to magnetic fields, RR of 1·82 (95% CI 1·25–2·65) for electric fields, and RR of 1·62 (95% CI 1·13–2·32) for pulsed electromagnetic fields. Occupational accidents related to power lines explain some of the excess of deaths from accidents and violence. Some association was found between magnetic fields and leukaemia, brain cancer, and suicide, between electric fields and brain cancer and suicide, and between pulsed electromagnetic fields and lung cancer, but these were not significant.**

***Conclusion*—These results are broadly reassuring that major causes of death are not strongly associated with exposure to electric and magnetic fields, but small numbers and approximate exposure assessments preclude the denial of any risk, in particular if it were to affect a rare cause of death.**

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Reports of symptoms such as headache, fatigue, and disruption of sleep patterns in extra high voltage switchyard workers occupationally exposed to extremely low frequency electric and magnetic fields appeared in the late 1960s.[1-3] Although these early cross sectional reports had methodological weaknesses, they started considerable public and scientific debate over the adverse health effects of occupational exposure to extremely low frequency electric and magnetic fields. Later, several epidemiological studies have suggested possible carcinogenic effects of such exposures. In particular, increased risks of leukaemia[4-10] and brain tumours[11-13] have been reported. Several review papers have been published on the association between occupational exposure to electric and magnetic fields and cancer.[14-16] Most of the earlier studies have been questioned for their design limitations, mainly because of crudeness of exposure assessments and small sample size.

More recently, studies of cancer with better exposure assessments have been carried out.[10 17 18] These showed some positive findings, but no one association was consistently found. Nearly all epidemiological studies have focused on cancer with no attention given to other causes of deaths.

Here we report the mortality of men who had worked in an electrical utility company in Québec, Canada. This cohort was one of three cohorts in which cancer incidence was investigated in the "Canada-France" case-control study.[17] Thus deaths from cancer in this study were included in the earlier study but deaths from other causes have not been included in any previous study.

Methods

STUDY POPULATION

The study population consisted of 21 744 male electrical utility workers who were employed at Hydro Québec, a state owned utility company covering the Canadian Province of Québec. To qualify, workers must have been employed between 1 January 1970 and 31 December 1988 and have worked at least one continuous year. Name, social insurance number, date of birth, date of hire, and date of departure and the title of the last job were obtained for each worker. For workers who were active at the study start date, the company computer files contained the above information. For the rest, the information was abstracted manually.

From the company records of current

employees and pensioners, 16 834 of the study subjects were known to be alive at the end of 1988. Also, from the company benefits records, 1539 men were known to have died before 1988. The remaining 3371 who had left the company during the follow up period were checked against provincial sources for mortality and live follow up (Regie de Rentes du Quèbec) and vital status was identified. Nine subjects had unknown vital status. For those found to have died, the causes of death (international classification of diseases (ICD) codes) were abstracted from the provincial death registration records. All codes from earlier revisions of the ICD were converted to those corresponding to the ninth revision (ICD-9).

ESTIMATION OF EXPOSURE

We used a job exposure matrix (JEM) to dichotomise jobs into background and above background groups, and to categorise the above background jobs into medium, high, and very high exposure categories. The JEM was developed for a large case-control study of cancer in company employees.[17] The matrix rows consisted of grouped job titles with similar expected exposures to extremely low frequency electric and magnetic fields. The grouping of job titles was done before the start of the study in consultation with company hygienists, an occupational physician, and health and safety committees. Exposures to 60 Hz electric and magnetic fields and pulsed electromagnetic fields were assessed for the grouped job titles from current exposure measurements made with the POSITRON exposure monitor (Positron Industries, Montréal, Québec Canada) worn over a working week by a stratified random sample (n = 466) of workers. The entry in each row of the JEM was the arithmetic mean of the weekly arithmetic means of all workers within the job category.[17]

As the full work histories were not readily available, we applied the JEM to the last job held. In this way, we classified workers into two exposure groups: background and above background. This was done separately for magnetic fields, electric fields, and pulsed electromagnetic fields. The background exposure group included all blue and white collar workers in the two categories of jobs identified initially as having background exposure and others with mean measured exposure less than or equal to the mean of the highest of the two initial background categories.

Standardised mortality ratios (SMRs) and exact Poisson 95% confidence intervals (95% CIs) were computed with the person-years analysis program prepared by the International Agency for Research on Cancer (IARC).[19]

Table 1 Job exposure matrix; mean exposure to 60 Hz magnetic, electric, and pulsed electromagnetic fields

		Magnetic fields μT		*Electric fields (V/m)*		*Pulsed electromagnetic fields (ppm)*	
Job group	*n*	*Mean*	*Exposure group*	*Mean*	*Exposure group*	*Mean*	*Exposure group*
Jobs considered initially to have background exposure:							
Blue collar jobs	3726	0·15	B	5·02	B	23·70	B
White collar jobs	9051	0·16	B	5·76	B	0·00	B
Hydroelectric generation:							
Equipment electricians	56	0·99	AB	18·21	AB	2·47	B
Equipment mechanics	586	0·77	AB	14·46	AB	4·06	B
Foremen	355	0·50	AB	12·42	AB	22·46	B
Operator	255	1·56	AB	6·34	AB	0·27	B
Nuclear generation:							
Equipment electricians	29	0·19	AB	2·82	B	0·00	B
Operator	59	0·13	B	2·52	B	0·00	B
Diesel generation:							
Operator	80	0·32	AB	4·82	B	9·38	B
Transmission:							
Splicer	22	1·79	AB	15·79	AB	63·12	AB
Linemen	168	0·60	AB	57·99	AB	63·22	AB
Substation:							
Equipment electrician	787	2·36	AB	52·13	AB	39·65	AB
Maintenance worker, civil, and mechanical engineer	605	1·05	AB	31·75	AB	0·01	B
Operator (mobile)	233	1·17	AB	12·04	AB	3·90	B
Operator (fixed)	213	1·78	AB	36·89	AB	3·56	B
Technician	338	1·60	AB	8·63	AB	0·03	B
Distribution:							
Emergency men	125	0·50	AB	12·71	AB	201·73	AB
Foremen, overhead lines	609	0·16	B	5·77	AB	35·44	AB
Foremen, underground lines	57	0·14	B	3·02	AB	417·95	AB
Linemen (contact and hotstick)	1918	0·37	AB	83·18	AB	74·76	AB
Meter installer	263	0·42	AB	5·47	B	0·14	B
Meter reader	337	0·17	AB	10·03	AB	0·00	B
Splicer	286	1·87	AB	9·73	AB	20·03	B
Tree trimmer	33	0·34	AB	37·51	AB	35·46	AB
Others:							
Estimator	315	0·13	B	4·31	B	0·00	B
Instructor	172	0·17	AB	2·83	B	0·00	B
Licensed electricians	50	0·87	AB	12·52	AB	0·46	B
Operator, dispatcher	534	0·09	B	3·16	B	0·03	B
Technician, telecommunication	184	0·44	AB	5·12	B	24·44	AB
Groundman (transport)	19	0·39	AB	31·90	AB	0·71	B
Total	21465						
Regrouping for this study:							
All background	14353	0·15	B	14429 5·42	B	17207 3·66	B
All above background	7112	0·94	AB	7036 38·12	AB	42586 3·94	AB

B = background; AB = above background.
Total number of subjects in the cohort is 21 744. The difference is due to 279 workers for whom there was no information on the last job held.

Table 2 SMRs and 95% CIs for major causes of death for male electrical utility workers: 1970–88, overall, and separately for blue and white collar workers

Cause of death* ICD-9	Total cohort†			Blue collar workers			White collar workers		
	Observed	SMR	95% CI	Observed	SMR	95% CI	Observed	SMR	95% CI
All causes	1582	0·75	0·71–0·79	885	0·78	0·73–0·83	577	0·64	0·59–0·69
Major causes:									
Neoplasms	466	0·83	0·76–0·91	275	0·91	0·80–1·02	165	0·69	0·59–0·80
Stomach	23	0·66	0·42–0·99	15	0·79	0·44–1·31	5	0·34	0·11–0·79
Large intestine, rectum	56	0·83	0·63–1·10	24	0·71	0·46–1·06	23	0·87	0·55–1·30
Liver and gall bladder	11	0·87	0·43–1·56	8	1·17	0·50–2·30	3	0·55	0·11–1·62
Pancreas	23	0·76	0·48–1·14	15	0·91	0·51–1·51	8	0·62	0·27–1·22
Trachea bronchus or lung	181	0·86	0·74–0·99	113	0·99	0·82–1·19	60	0·67	0·51–0·86
Male genitalia	15	0·54	0·30–0·89	10	0·66	0·32–1·22	5	0·44	0·14–1·03
Urinary	26	1·04	0·68–1·53	14	1·04	0·57–1·74	11	1·04	0·52–1·87
Brain	20	1·13	0·69–1·75	10	1·06	0·51–1·94	9	1·16	0·53–2·20
Non-Hodgkin's lymphoma	18	1·02	0·61–1·63	8	0·85	0·37–1·68	10	1·31	0·63–2·41
Leukaemia	20	1·05	0·64–1·62	11	1·07	0·53–1·91	6	0·73	0·27–1·59
Endocrine and nutritional	24	0·55	0·35–0·81	12	0·51	0·26–0·88	6	0·32	0·12–0·70
Nervous system diseases	18	0·69	0·41–1·08	9	0·63	0·29–1·20	9	0·79	0·36–1·51
Circulatory diseases	625	0·71	0·66–0·77	317	0·67	0·60–0·75	255	0·68	0·60–0·77
Respiratory diseases	68	0·60	0·47–0·77	38	0·62	0·44–0·86	20	0·43	0·26–0·66
Digestive diseases	68	0·67	0·52–0·85	42	0·77	0·56–1·05	22	0·50	0·31–0·75
Genitourinary diseases	12	0·68	0·35–1·19	7	0·73	0·29–1·51	3	0·41	0·08–1·19
Deaths due to accidents and violence	191	0·64	0·55–0·73	125	0·76	0·64–0·91	55	0·41	0·31–0·54
Suicide	49	0·56	0·41–0·71	31	0·64	0·44–0·92	18	0·46	0·27–0·73
Motor vehicle accidents	60	0·63	0·48–0·81	37	0·70	0·50–0·89	18	0·43	0·28–0·68

*Cause of death included in the table if the total number of observed deaths > 5.
†Includes 120 observed deaths with no information on the last job held, therefore the total number of observed deaths in this column are sometimes greater than the total number of observed deaths from the columns of blue collar and white collar groups.

Age, year, and cause specific mortalities of Québec men were applied to the person-years of the cohort to assess expected deaths.

We calculated the estimates of rate ratios (RRs) in the exposed group relative to the background group and 95% CIs with Poisson regression analysis. The EPICURE[20] program was used for this purpose. Age and calender year were entered in the model as categorical variables in five year interval groups.

Results

Of all 21 744 men in the cohort 1582 (7·28%) had died by the end of follow up. Only nine (0·04%) were lost to follow up. The mean length of follow up was 12·9 years. The mean age at hire was 26·2 years, the mean age at death or end of follow up was 46·1 years.

Table 1 shows the mean exposures of each job category in the JEM and also the classification of each job category to the background or above background groups. The mean exposures for electric and magnetic fields and pulsed electromagnetic fields in the background groups were 5·42 V/m, 0·15 μT, and 3·66 ppm, and in the above background groups they were 38·12 V/m, 0·94 μT, and 3·94 ppm.

Table 2 shows SMRs for major causes of deaths overall and for blue and white collar workers separately. None were more than marginally above one. Most were less than one.

Because above background exposure was exclusively among blue collar workers, the remainder of the results were restricted to them. Table 3 shows SMRs according to the following broad categories of the last job held by the worker: generation (power plant) work-

Table 3 SMRs and 95% CIs for major causes of death for male electrical utility workers: 1970–88 by job categories for blue collar workers

Cause of death ICD-9	All generation (power plant) workers (hydroelectric, nuclear, diesel)			Linemen*			Substation workers			Electricians		
	Observed	SMR	95% CI	Observed	SMR	95% CI	Observed	SMR	95% CI	Observed	SMR	95% CI
All causes	144	0·86	0·73–1·02	150	0·79	0·67–0·93	96	0·64	0·52–0·78	43	0·83	0·61–1·13
Major causes:												
Neoplasms	44	0·96	0·70–1·30	45	0·91	0·67–1·22	32	0·81	0·56–1·16	9	0·69	0·32–1·32
Stomach	1	0·34	0·01–1·90	1	0·33	0·01–1·88	3	1·27	0·26–3·73	0	—	—
Large intestine, rectum	2	0·39	0·05–1·40	5	0·92	0·30–2·15	2	0·47	0·06–1·68	2	1·39	0·17–5·03
Liver and gall bladder	2	1·92	0·23–6·93	0	—	—	1	1·13	0·03–6·29	0	—	—
Pancreas	3	1·20	0·25–3·51	3	1·13	0·23–3·32	4	1·89	0·52–4·85	1	0·79	0·02–4·40
Trachea, bronchus or lung	16	0·79	0·53–1·50	24	1·29	0·82–1·91	10	0·67	0·32–1·23	2	0·42	0·05–1·53
Male genitalia	2	0·71	0·10–2·86	1	0·48	0·01–2·69	0	—	0·00–2·67	0	—	—
Urinary	0	—	—	3	1·42	0·29–4·14	3	1·77	0·37–5·18	0	—	—
Brain	5	3·90	0·26–9·10	2	0·58	0·01–3·23	0	—	—	2	4·55	0·55–16·45
Non-Hodgkin's lymphoma	2	1·49	0·18–5·39	2	1·24	0·15–4·47	0	—	—	1	2·34	0·06–13·05
Leukaemia	2	1·38	0·17–4·99	1	0·56	0·01–3·14	3	2·16	0·45–6·33	0	—	—
Endocrine and nutritional	3	0·84	0·17–2·45	0	—	—	1	0·33	0·01–1·85	2	1·06	0·13–3·85
Nervous system diseases	2	0·99	0·12–3·59	1	0·41	0·01–2·28	0	—	—	1	0·95	0·02–5·30
Circulatory diseases	52	0·71	0·53–0·94	40	0·53	0·38–0·73	28	0·47	0·31–0·68	15	0·74	0·41–1·22
Respiratory diseases	6	0·60	0·22–1·31	1	0·11	0·00–0·62	7	0·94	0·38–1·95	2	0·75	0·09–2·72
Digestive diseases	5	0·64	0·21–1·49	5	0·59	0·17–1·23	8	1·11	0·48–2·19	3	1·28	0·03–7·09
Genitourinary diseases	1	0·67	0·02–3·70	2	1·39	0·17–5·03	2	1·75	0·21–6·32	1	2·38	0·06–13·80
Deaths due to accidents and violence	20	1·08	0·66–1·67	43	1·30	0·95–1·76	12	0·47	0·24–0·83	10	1·02	0·49–1·87
Suicide	5	0·94	0·30–2·29	7	0·71	0·28–1·46	2	0·25	0·03–0·93	3	0·33	0·01–1·84
Motor vehicle accidents	7	1·21	0·49–2·49	10	0·92	0·44–1·70	6	0·73	0·27–1·58	3	0·92	0·19–2·68

*Transmission and distribution linemen combined.

Table 4 SMRs, RRs, and 95% CIs for major causes of death for male electrical utility workers: 1970–88, overall, and by level of magnetic fields, for blue collar workers only

Cause of death* ICD-9	Exposure level (magnetic fields): Background† ≤ 0·16 μT			Above background > 0·16 μT				
	Observed	SMR	95% CI	Observed	SMR	95% CI	RR‡	95% CI
All causes	449	0·75	0·68–0·82	436	0·81	0·74–0·89	1·11	0·97–1·27
Major causes:								
Neoplasms	143	0·88	0·75–1·04	132	0·93	0·78–1·11	1·07	0·84–1·36
Stomach	9	0·88	0·40–1·66	6	0·70	0·26–1·51	0·82	0·29–2·32
Large intestine, rectum	13	0·71	0·38–1·22	11	0·71	0·35–1·26	0·98	0·44–2·20
Liver and gall bladder	3	0·82	0·17–2·40	5	1·57	0·51–3·66	1·86	0·44–7·85
Pancreas	5	0·57	0·18–1·33	10	1·31	0·63–2·41	2·36	0·80–6·93
Bronchus and lung	63	1·04	0·80–1·33	50	0·93	0·70–1·24	0·93	0·63–1·36
Male genitalia	5	0·58	0·19–1·36	5	0·77	0·25–1·79	1·42	0·40–4·97
Urinary	8	1·09	0·47–2·15	6	0·97	0·36–2·12	0·94	0·32–2·74
Brain	3	0·62	0·13–1·83	7	1·50	0·60–3·09	2·48	0·64–9·62
Non-Hodgkin's lymphoma	5	1·02	0·33–2·38	3	0·67	0·14–1·95	0·64	0·15–2·71
Leukaemia	5	0·94	0·30–2·19	6	1·21	0·44–2·64	1·41	0·42–4·66
Endocrine and nutritional	5	0·39	0·13–0·92	7	0·64	0·26–1·31	1·25	0·36–4·37
Nervous system diseases	6	0·82	0·30–1·78	3	0·44	0·09–1·28	0·56	0·14–2·25
Circulatory diseases	180	0·70	0·60–0·81	137	0·63	0·53–0·74	0·91	0·73–1·14
Respiratory diseases	24	0·70	0·45–1·05	14	0·51	0·28–0·86	0·86	0·44–1·66
Digestive diseases	22	0·77	0·48–1·17	20	0·77	0·47–1·19	1·03	0·56–1·89
Genitourinary diseases	2	0·38	0·05–1·37	5	1·17	0·38–2·74	2·87	0·55–14·87
Deaths due to accidents and violence	39	0·51	0·36–0·70	86	0·99	0·80–1·23	2·00	0·37–2·93
Suicide	11	0·50	0·30–1·02	20	0·77	0·47–1·19	1·72	0·82–3·59
Motor vehicle accidents	13	0·53	0·28–0·91	24	0·85	0·55–1·27	1·66	0·84–3·27

*Cause of death included in the table if the total number of observed deaths > 5.
†Value of the background blue or white collar workers whichever is greater.
‡RRs from Poisson regression analysis.

ers (n = 1420), substation workers (n = 2176), linemen (n = 2086), and electricians (n = 922). The only nominally significant (at P < 0·05, two sided) excess was for brain cancer among generation (power plant) workers (SMR = 3·90, 95% CI 1·26–9·10). Brain cancer mortality was also raised among electricians but not significantly so. There was a deficit of brain cancer deaths in linemen and substation workers. Tables 4–6 show SMRs for major causes of deaths by level of each of magnetic, electric, and pulsed electromagnetic fields (background and above background) and the estimates of RRs for above background group relative to the background group. The SMRs were generally less than one, most likely resulting from factors related to the healthy worker effect. None was close to being significantly increased.

We found some association between magnetic fields and leukaemia, brain cancer, and suicide, between electric fields and brain cancer and suicide, between pulsed electromagnetic fields and lung cancer, and between all three indices and pancreatic cancer, but RRs were not significant.

Only for deaths due to accidents and violence were the RRs significantly above one (at P < 0·05, two sided): RR = 2·00 (95% CI 1·37–2·93) with magnetic fields, RR = 1·82 (95% CI 1·25–2·65) with electric fields, and RR = 1·62 (95% CI 1·13–2·32) with pulsed electromagnetic fields.

Fifteen out of the 123 total deaths due to

Table 5 SMRs, RRs, and 95% CIs for major causes of death for male electrical utility workers: 1970–88, overall, and by level of electric fields, for blue collar workers only

Cause of death* ICD-9	Exposure level (electrical fields): Background† ≤ 5·76 volts/meter			Above background > 5·76 volts/meter				
	Observed	SMR	95% CI	Observed	SMR	95% CI	RR‡	95% CI
All causes	449	0·78	0·71–0·85	436	0·78	0·71–0·85	1·03	0·90–1·17
Major causes:								
Neoplasms	137	0·88	0·74–1·05	138	0·93	0·78–1·10	1·07	0·84–1·36
Stomach	10	1·02	0·49–1·87	5	0·55	0·18–1·29	0·56	0·19–1·64
Large intestine, rectum	12	0·69	0·36–1·20	12	0·73	0·38–1·28	1·06	0·46–2·38
Liver and gall bladder	4	1·14	0·31–2·92	4	1·20	0·33–3·06	1·02	0·25–4·09
Pancreas	4	0·48	0·13–1·22	11	1·36	0·69–2·46	2·96	0·94–9·33
Trachea, bronchus or lung	54	0·93	0·70–1·22	59	1·05	0·80–1·36	1·14	0·78–1·68
Male genitalia	6	0·73	0·27–1·59	4	0·58	0·16–1·49	0·86	0·24–3·09
Urinary	7	1·00	0·40–2·06	7	1·08	0·43–2·22	1·16	0·40–3·35
Brain	4	0·86	0·24–2·21	6	1·24	0·46–2·71	1·47	0·41–5·21
Non-Hodgkin's lymphoma	4	0·85	0·23–2·17	4	0·85	0·23–2·19	0·99	0·24–3·97
Leukaemia	6	1·16	0·43–2·53	5	0·98	0·32–2·28	0·92	0·28–3·02
Endocrine and nutritional	8	0·49	0·18–1·07	5	0·52	0·19–1·14	0·73	0·20–2·62
Nervous system diseases	4	0·56	0·15–1·44	5	0·71	0·23–1·65	1·27	0·34–4·76
Circulatory diseases	187	0·76	0·66–0·88	130	0·76	0·66–0·88	0·76	0·61–0·95
Respiratory diseases	22	0·67	0·42–1·02	16	0·56	0·32–0·90	0·96	0·50–1·84
Digestive diseases	22	0·80	0·50–1·22	20	0·74	0·45–1·14	0·94	0·51–1·73
Genitourinary diseases	2	0·39	0·05–1·43	5	1·12	0·36–2·61	2·59	0·50–13·39
Deaths due to accidents and violence	41	0·54	0·39–0·73	84	0·96	0·77–1·20	1·82	1·25–2·65
Suicide	11	0·50	0·25–0·89	20	0·77	0·47–1·19	1·64	0·78–3·43
Motor vehicle accidents	12	0·49	0·25–0·86	25	0·89	0·58–1·31	1·87	0·93–3·72

*Cause of death included in the table if the total number of observed deaths > 5.
†Value of the background blue or white collar workers whichever is greater.
‡RRs from Poisson regression analysis.

Table 6 SMRs, RRs, and 95% CIs for major causes of death for male electrical utility workers: 1970–88, overall, and by level of pulsed electromagnetic fields, for blue collar workers only

	Exposure to pulsed electromagnetic fields							
	Background† ≤ *23·70 ppm*			*Above background* > *23·70 ppm*				
Cause of death ICD-9*	*Observed*	*SMR*	*95% CI*	*Observed*	*SMR*	*95% CI*	*RR*‡	*95% CI*
All causes	663	0·79	0·73–0·85	222	0·75	0·65–0·85	0·98	0·84–1·47
Major causes:								
Neoplasms	207	0·91	0·79–1·05	68	0·88	0·69–1·12	1·00	0·76–1·32
Stomach	14	0·98	0·53–1·64	1	0·22	0·01–1·22	0·23	0·03–1·77
Large intestine, rectum	19	0·75	0·45–1·17	5	0·60	0·19–1·39	0·79	0·29–2·13
Liver and gall bladder	8	1·56	0·67–3·27	0	0·00	0·00–2·29	—	—
Pancreas	9	0·73	0·33–1·39	6	1·46	0·54–3·18	2·25	0·79–6·45
Trachea, bronchus or lung	78	0·91	0·73–1·15	35	1·21	0·85–1·69	1·27	0·83–1·94
Male genitalia	8	0·67	0·29–1·32	2	0·63	0·08–2·29	1·12	0·23–5·41
Urinary	10	0·98	0·47–1·80	4	1·22	0·33–3·13	1·37	0·42–4·49
Brain	9	1·34	0·61–2·54	1	0·36	0·01–2·04	0·29	0·04–2·21
Non-Hodgkin's lymphoma	5	0·73	0·24–1·70	3	1·18	0·24–3·45	1·56	0·36–6·67
Leukaemia	9	1·20	0·55–2·28	2	0·71	0·09–2·58	0·67	0·14–3·18
Endocrine and nutritional	10	0·56	0·27–1·03	2	0·33	0·04–1·22	0·37	0·04–2·94
Nervous system diseases	6	0·58	0·21–1·26	3	0·79	0·16–2·28	1·36	0·33–5·55
Circulatory diseases	249	0·69	0·61–0·79	68	0·58	0·46–0·74	0·87	0·66–1·14
Respiratory diseases	37	0·78	0·55–1·08	1	0·07	0·00–0·43	0·12	0·02–0·88
Digestive diseases	34	0·85	0·60–1·20	8	0·54	0·23–1·07	0·66	0·30–1·43
Genitourinary diseases	5	0·68	0·22–1·58	2	0·91	0·11–3·27	1·19	0·22–6·27
Deaths due to accidents and violence	70	0·64	0·50–0·81	55	1·02	0·77–1·33	1·62	1·13–2·32
Suicide	19	0·60	0·36–0·93	12	0·74	0·38–1·29	1·33	0·64–2·75
Motor vehicle accidents	24	0·69	0·44–1·03	13	0·74	0·39–1·26	1·01	0·56–2·19

*Cause of death included in the table if the total number of observed deaths > 5.
†Value of the background blue or white collar workers whichever is greater.
‡RRs from Poisson regression analysis.

accidents and violence were accidents caused by electrocution (ICD-9, E925). All of these 15 held a last job classified as exposed above background level to magnetic fields. Nine of them were coded as E925·1: "electrical accidents related to power lines in electrical power generating plants and distribution stations". The other six deaths may also have been due to occupational electrocution even though not coded as such. Thirteen of the 15 deaths of workers exposed to electric fields, and 12 out of 15 deaths of workers exposed to pulsed electromagnetic fields had exposures above background. Thus electrocutions explain some but not all the excess in the above background groups from deaths due to accidents and violence.

For cause of deaths for which the RRs were significantly increased (accidents and violent deaths) and those in which there was initial

Table 7 RRs and 95% CIs for four exposure groups for blue collar electrical utility workers only: 1970–88

	Magnetic fields (μT)											
	Background ≤ *0·16 (mean = 0·16)*		*Medium 0·17–0·49 (mean = 0·40)*			*High 0·50–1·55 (mean = 1·03)*			*Very high* ≥ *1·56 (mean = 2·07)*			
	O	*RR*	*O*	*RR*	*95% CI*	*O*	*RR*	*95% CI*	*O*	*RR*	*95% CI*	*P value test for trend two sided*
Leukaemia	5	1	3	1·59	(0·37–6·79)	1	0·61	(0·07–5·21)	2	3·00	(0·57–15·98)	> 0·20
Brain cancer	3	1	2	1·44	(0·24–8·67)	5	4·88	(1·16–20·47)	0	—	—	> 0·20
Deaths due to accidents and violence	39	1	56	2·53	(1·67–3·82)	21	1·74	(1·02–2·96)	9	1·00	(0·49–2·09)	> 0·20
Suicide	11	1	13	2·19	(0·98–4·91)	4	1·13	(0·36–3·56)	3	1·38	(0·38–5·00)	> 0·20
Motor vehicle accidents	13	1	12	1·60	(0·72–3·52)	9	2·28	(0·97–5·36)	3	0·96	(0·27–3·42)	> 0·20
	Electric fields (V/m)											
	Background ≤ *5·76 (mean = 5·42)*		*Medium 5·77–31·74 (mean = 11·22)*			*High 31·75–83·18 (mean = 44·00)*			*Very high* ≥ *83·19 (mean = 83·19)*			
	O	*RR*	*O*	*RR*	*95% CI*	*O*	*RR*	*95% CI*	*O*	*RR*	*95% CI*	*P value test for trend two sided*
Leukaemia	6	1	3	0·91	(0·23–3·65)	1	0·80	(0·10–6·71)	1	1·09	(0·12–9·39)	> 0·20
Brain cancer	4	1	5	2·15	(0·58–8·02)	0	—	—	1	1·25	(0·13–11·33)	> 0·20
Deaths due to accidents and violence	41	1	35	1·44	(0·92–2·26)	11	1·12	(0·57–2·17)	38	3·29	(2·10–5·15)	< 0·0001
Suicide	11	1	13	1·99	(0·89–4·44)	2	0·72	(0·16–3·26)	5	1·72	(0·59–4·98)	> 0·20
Motor vehicle accidents	12	1	12	1·70	(0·76–3·79)	4	1·48	(0·45–4·34)	9	2·61	(1·09–6·27)	= 0·04
	Pulsed electromagnetic fields (V/m)											
	Background ≤ *23·70 (mean = 3·66)*		*Medium 23·71–63·20 (mean = 34·46)*			*High 63·21–74·74 (mean = 63·21)*			*Very high* ≥ *74·75 (mean = 89·51)*			
	O	*RR*	*O*	*RR*	*95% CI*	*O*	*RR*	*95% CI*	*O*	*RR*	*95% CI*	*P value test for trend two sided*
Leukaemia	9	1	1	0·56	(0·07–4·49)	0	—	—	1	0·90	(0·11–7·39)	> 0·20
Brain cancer	9	1	0	—	—	0	—	—	1	0·70	(0·09–5·62)	> 0·20
Lung cancer	78	1	18	1·11	(0·65–1·89)	1	1·54	(0·21–11·10)	16	1·53	(0·85–2·74)	= 0·12
Deaths due to accidents and violence	70	1	15	0·87	(0·50–1·53)	1	0·96	(0·13–6·94)	39	2·53	(0·61–3·85)	< 0·0001
Suicide	19	1	6	1·25	(0·50–3·13)	0	—	—	6	1·53	(0·58–3·63)	> 0·20
Motor vehicle accidents	24	1	4	0·68	(0·24–1·96)	0	—	—	9	1·66	(0·76–3·60)	> 0·20

O = observed.

interest (leukaemia, brain cancer, lung cancer, and suicide) we further subdivided subjects into four categories by exposure (table 7). We used the median and the 75th percentiles of the above background values as boundaries between these exposure groups.

Most of the associations did not show very convincing exposure-response gradients. One should note here that duration of exposure could not be calculated for the trend analysis. Risk of lung cancer did increase steadily with exposure to pulsed electromagnetic fields, but only to a maximum of 1·54, a trend which was not significant (P = 0·12). Risk of deaths due to accidents and violence was concentrated in the group with very high exposure to electric fields and pulsed electromagnetic fields, and both showed a significant trend (P < 0·0001). This is probably partly due to electrocutions, but apparently also to a small extent to motor vehicle accidents.

Discussion

Analysis of mortality of 21 744 electrical utility workers provided no evidence of increased mortality overall. Death rates were substantially below those of the Québec male population, with an SMR of 0·75 for all causes and 0·83 for all cancers. The SMRs for major causes of death and for site specific cancers were also less than one. These low SMRs probably resulted from a healthy worker effect,[21] as these men were all fit enough to work in 1970 and later. Similar results have been reported in other studies of occupational cohorts, especially with duration of follow up as low as in this study.

The low SMRs might have also resulted from the underassessment of mortality. We would expect assessment to be poorest in men leaving the company without pension rights. Thus, we investigated this possible source of bias further by calculating SMRs by three categories of work activity: active, retired, and those who left without a pension. The SMRs and 95% CIs were 0·62 (0·57–0·66), 0·92 (0·87–1·00), and 0·64 (0·46–0·85) respectively. The low SMR in active workers could be explained by the healthy worker effect. The SMR of 0·64 among leavers suggests a possible underassessment of mortality in this group, but the total number of workers was small in this group (observed deaths = 41, expected deaths = 65·65), so that resulting bias in the complete cohort would have been very small.

To obtain complete job histories for the entire cohort was not feasible in this study so we had to rely on last job. Obviously, the last job does not represent the total work experience of a worker. Non-differential misclassification, biasing the results toward the null value, will have resulted from the use of the last job only to classify workers into exposure categories. A recent case-control study of leukaemia in telephone linemen[22] showed 85% agreement between last job and longest job. We had similar findings in a validation study carried out on our cohort which showed exposure estimated from last job correlated at r = 0·78 with exposure estimated from all jobs, in a sample of workers.[23] In particular, although not all workers who started in highly exposed jobs stayed in them, workers who ended their working life in highly exposed jobs had usually been in these jobs throughout their working life. Last job was particularly good for identifying the most highly exposed workers. Thus, although some highly exposed workers may still be placed in the background group, our results for the high and very high exposure groups are likely to be the least affected by exposure misclassification.

Other sources of errors are approximations in estimating means in the JEM and misclassifications of workers due to the variations between workers in the same row of the JEM. Again, the effect of these misclassifications will have been to bias the risk estimates toward the null value. Nevertheless, the difference between mean exposures of the background and above background groups was substantial even allowing for some misclassification.

The increased risk of deaths due to accidents and violence in the above background exposure groups is due in part to electrocutions at work. It may be that other work related accidents played a part. An effect of exposure to electric and magnetic fields on accidents through impairing mental function, perhaps by disrupting circadian rhythm, would be consistent with some effects of these fields found experimentally,[24 25] but this remains speculation. There was some weak evidence for an increased risk of suicide among workers exposed to all field types. Because an effect of extremely low frequency electric and magnetic fields on suicide has been suggested by other researchers[26 27] the suicides in this study have been studied further in a case cohort study, published separately.[28]

The incidence of cancers in this cohort, and others from France and Ontario, was the focus of the Canada-France case-control study.[17] For most anatomical sites of cancer, in particular brain and leukaemia, numbers in this cohort on its own were too small for the risk estimates to be very useful, and readers are directed to the results of the Canada-France study.

The results for lung cancer and pulsed electromagnetic fields are of particular interest given the strong association found in the Quebec component of the Canada-France case control study.[29] The exposures to pulsed electromagnetic fields were recorded on the POSITRON meters' third channel. This was designed to reflect high frequency (5–20 MHz) pulses of electromagnetic energy (> 200 V/m), but has been shown also to respond to bursts of portable radio transmissions of lower amplitude at up to 400 MHz.[24] The association with lung cancer is found in the present study, but it is much weaker than that found in the case-control study. The association is weakened here at least in part by exposure being based on only the last job, and some of the difference may be due to the greater control of confounders in the case-control study.

The index of exposure to pulsed electromagnetic fields used in this study (mean ppm), is also different from that used in the case-control study (workers (%) > 0·1 ppm), and may have been more subject to error. However, the absence of an overall increased SMR for lung cancer weighs in as evidence against the existence of a causal association, at least one as strong as that found in the case-control study (RR > 3·00 for all groups above median exposure), a point that has been discussed further in the report of the case-control study.[29]

The increased SMRs for brain cancer among extremely low frequency power plant workers and electricians were not clearly explained by estimated exposure to any of the three fields investigated. However, workers exposed to magnetic fields at above background levels had an increased mortality compared with those exposed at background levels (RR = 2·48, 95% CI 0·64–9·62, table 4). This excess was particularly pronounced in those in the high exposure category (RR = 4·88, 95% CI 1·16–20·47, table 7), but there were no deaths in the very high category. When two groups were combined RR was diminished to 3·43 (95% CI 0·82–14·38). The Canada-France case-control study[17] included the brain cancer deaths studied here. The case-control study had better exposure estimates, as complete work histories were obtained. The study showed an increased risk, but not significantly so, of brain cancer for workers whose cumulative exposure to magnetic fields was above the 90th percentile (OR = 1·95, 95% CI 0·76–5·00). The most recent United States study of electrical utility workers[18] showed a significant association between brain cancer and workers in the highest exposure category to magnetic fields (RR = 2·29 95% 1·15–4·56). Our finding of an increased risk of brain cancer for power plant workers (table 3) is not consistent with the United States study,[18] which found no excess in this group, but non-significantly increased RRs for linemen (1·21) and electricians (1·64). We found an excess among electricians (RR = 4·55, 95% CI 0·55–16·45), but this was based on only two deaths, and was far from being significant.

Given the bias towards the null value discussed above, interpretation of the absence of associations of mortality from most causes with electric and magnetic fields should be cautious. Nevertheless, it is reassuring that no increased mortality was found in the groups with above background exposure for the major causes of death, of which only cancer has been previously studied.

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