

ELECTROMAGNETIC FIELDS EXPOSURE AND BRAIN TUMORS

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ABSTRACT

An epidemiologic study was conducted on occupation and industry entries listed on the death certificates of 951 adult white male Maryland residents who died from brain tumor between 1969 and 1982. Compared to controls who were matched with the cases on age and date of deaths and who died of causes other than malignancy, a significantly higher proportion of primary brain tumor persons (gliomas and astrocytomas) was found to have been employed in electrical occupations such as electrician, electric or electronic engineer, and utility company serviceman. To further explore the relationship, the occupations of cases and controls were grouped according to a level of potential job exposure to electromagnetic (E-M) fields i.e., definite, probable, possible and no exposure. An increase in the odds ratio for brain tumor was found to be positively related to potential E-M exposure levels. Furthermore, the mean age at death was found significantly younger among the cases in the presumed definite E-M exposure group than those with no apparent E-M exposure group. Similar findings of an increase of brain tumors in electrical workers have been reported elsewhere. These findings suggest that E-M exposure may be associated with the pathogenesis of brain tumors, particularly in the promoting stage.

KEY WORDS:

Brain Tumors; Death Certificates; Electrician; Electromagnetic Fields; Non-ionizing Radiation; Occupation; Oncogenesis

In recent years, several epidemiological studies have suggested that environmental factors may be related to the occurrence of brain tumors. Specifically, concern has been raised over the possibility of increased risk of brain tumor among employees in the petrochemical industry (1,2). A few studies on workers of some refineries suggest that petrochemical compounds such as vinyl chloride may be responsible for the increase (3-5). However, other studies showed no significant increase in brain tumor deaths among petrochemical industry employees (6-8).

The current study, utilizing vital records in the State of Maryland for 1969-1982, was conducted to further explore the association between occupation and brain tumor mortality.

MATERIALS AND METHODS

Death certificates of white male Maryland residents, aged 20 and over, were collected from the following ICD Codes for review:

ICD 8 (1969 - 1978)	ICD 9 (1979 - 1982)	TYPE OF TUMOR
191	191.0 - 191.9	Malignant neoplasm of brain
192.9		Malignant neoplasm of other part of nervous system, site unspecified
225.0	225.0	Benign neoplasm of brain
238.1	239.6	Neoplasm of unspecified nature, brain

All females and black males were not included because of the relative lack of occupational information on their death certificates.

From the total of 1,043 death certificates collected, ninety-two certificates were excluded. Sixty-eight were metastatic tumors from other sites and twenty-four were rare brain tumors such as melanoma, lymphoma, medulloblastoma and ventricular tumor. Rare brain tumors were excluded because of their different histopathology and natural history, which could introduce a bias in a study of gliomas (9).

As a result, 951 brain tumor deaths were included in this study: 370 glioma or glioblastoma multiforme, 149 astrocytomas, and 432 brain tumors (histologic type not specified). It is suspected that some of the non-specified brain tumors may be secondary tumors or other rare types of brain tumors. Table 1 shows the distribution of cases by the type and ICD code on the certificates. Because of the overlap between the ICD codes and different histologic types of brain tumors, subsequent analyses were based on the histologic type recorded on the death certificate and not on ICD code. Gliomas and astrocytomas were grouped together as a single category of primary brain tumor. Brain tumors with histologic type not specified were treated as a separate category in the analysis. (Table 1 about here)

Occupations recorded on death certificates among brain tumor deaths were compared to those of a control group of death certificates of white adult male Maryland residents with causes of death other than malignant neoplasms. Controls were matched with the cases on age (± 1 year) and date of death (as close to the case as possible) and were selected from a ten per cent computer-randomized roster of Maryland deaths.

Statistical significance was assessed using a chi-square test on the distribution of various occupations, the t-test on age distribution as

well as 95 per cent confidence intervals around the odds ratios using the logit method (10).

RESULTS

Table 2 shows the age distribution of the 951 white male brain tumor deaths by histologic type. The peak age is in the 60-69 year age group of all three types of brain tumors. The mean age at death for the glioma and astrocytoma groups is similar. However, it is higher for the non-specified brain tumor group which may be a result of the inclusion of secondary brain tumor cases in the latter. (Table 2 about here)

Preliminary analysis of the data on cases disclosed a disproportionate representation of workers employed in occupations associated with electricity or electromagnetic fields. In Table 3, the number of deaths in each of these occupational groups is compared to the number expected based on the proportion of these occupations surveyed and reported in the 1970 Maryland population census. There is a greater-than-expected number of brain tumor deaths in all of these occupational groups, especially for the glioma/astrocytoma group. These data, however, may be biased because they represent the prevalence of these occupations at one point in time (1970 census), whereas the mortality data span a 14-year period. Also age is not adjusted. In addition, some differences may be attributable to occupation recording practices for the census as compared to death certificates. (Table 3 about here)

To overcome this possible bias, a case-control study was conducted. Death certificates were obtained from a control group of white adult Maryland residents who died from causes other than malignancy, matched with the cases on age and date of death. Table 4 presents the case/control comparison of occupational distribution for several occupational groups.

(Table 4 about here)

Occupations related to electricity or apparent exposure to electromagnetic fields showed an excess representation among the cases of the glioma/astrocytoma group as compared with the controls; but no significant differences were noted between the cases and controls in the non-specified brain tumor group. No significant excess of brain tumor deaths was found in the petrochemical industries, although the numbers were small. There were only twelve cases in this job category, as compared with ten controls.

Based on these preliminary findings, occupations were then grouped according to level of possible exposure to electromagnetic fields -- i.e., definite, probable, possible or no exposure. Exposure category for each occupation was determined in consultation with an industrial hygienist, an occupational physician and a radiation physicist. Since there are no available data on duration of occupational exposure on death certificates, the categories of electromagnetic fields exposure are based simply on job title and industry entry. Table 5 shows the rankings. Cases and controls were assigned to categories independently by two persons blinded as to their status. Any discrepancies in ranking were solved by a third opinion.

(Table 5 about here)

Table 6 shows an analysis of case/control differences based on these exposure categories for glioma and astrocytoma. There are twenty-seven cases as compared with fourteen controls in category A (definite E-M exposure), and twenty-one cases versus twelve controls in category B (probable E-M exposure), a significant difference. The odds ratios for these two exposure groups are 2.15 and 1.95, respectively. It is of interest to note that there is an increase in the odds ratio positively related to E-M exposure levels. However, only the categories A and C have 95 per cent confidence intervals above 1.0. Table 7 presents the same analysis for non-specified brain tumors. Although there are a greater number of cases than controls in both

categories A and B, but none of them has an odds ratio significantly different from 1.0. (Tables 6 and 7 about here)

Table 8 shows the mean age at death of the cases by E-M exposure category. Cases of glioma/astrocytoma group in the "definitely E-M exposure" category died at significantly younger ages than those with no E-M exposure (mean age 52.8 versus 57.9, respectively, $P < 0.05$). However, there are no significant differences in mean age at death, by E-M exposure levels, in those with non-specified brain tumors.

(Table 8 about here)

DISCUSSION

Weaknesses of death certificate data as material for epidemiologic studies are widely acknowledged (11). However, as a source for generating hypotheses regarding occupational or industrial hazards associated with specific types of cancer, such data can be quite valuable. The difficulty with the small numbers of cancer cases often met in retrospective and prospective epidemiologic studies can be overcome in mortality statistics studies by combining related occupational categories and by analyzing data from a larger time period.

In the present study, there were two possible sources of error: 1) misdiagnosis or misclassification of cause of death, and 2) misclassification of occupation. The first type of error is probably less common for brain tumors than for other cancers since both malignant and benign brain tumors usually result in death (12). In a study of the accuracy of death certificates, mortality rates for brain tumors were judged to be among the most accurate based on both detection and confirmation (11). Two measures were taken in order to reduce error in including secondary brain tumor cases. First, all death certificates collected were reviewed by the authors (RL and PD). Any death certificates that indicated that the brain

tumor was due to metastasis were removed from the analysis. Second, cases were classified according to histologic type, i.e., glioma or glioblastoma multiforme, astrocytoma, and non-specified "brain cancer" or "brain tumor". Gliomas and astrocytomas, diagnosed either by biopsy or autopsy, were considered as primary brain tumors. Analyses were performed separately for the group of non-specified brain tumors.

Errors stemming from occupational misclassification may come from several sources: inaccuracies as a result of lack of knowledge of next-of-kin, or incomplete information. The underlying assumption of our study was that the recorded occupation was the principal job and that the duration of exposure was sufficient to cause an effect in the decedent's health. However, since the information on occupation of controls was also obtained from death certificates, the potential for error should be shared equally by cases and controls (13).

Mortality data from the State of Maryland shows an association between primary brain tumor and employment in occupations with exposures to potentially high electromagnetic fields. Several studies in the literature have also mentioned a higher risk of brain tumor among electrical and maintenance workers, but the majority of such findings have been reported as part of a particular industry study, such as the petrochemical industry. Generally, researchers concentrated on hypotheses linking brain tumors to chemical exposures. In a study in Los Angeles, Preston-Martin and coworkers found a significant increase in brain tumors among electricians and engineers, particularly aircraft employees (14). The authors, however, concluded that the data "fail to implicate any specific exposures within the (aircraft) industry that might be important etiologically, since the majority of workers were classified at diagnosis as engineers

or some other type of white collar worker."

In another epidemiologic study of CNS tumors conducted among industrial workers in Ohio, Mancuso also observed that individuals working with electrical machinery had the highest CNS tumor mortality rate (15). Nicholson et al. (16) reported an excess of brain tumors among operating engineers in chemical and petrochemical industries in Texas and Louisiana. The category of operating engineers included stationary engineers, stationary firemen, and construction engineers who were engaged in the operation and maintenance of heavy equipment.

Alexander et al. (2) reported on an investigation of an apparent increased prevalence of brain tumors in a Texas petrochemical plant. Although examination of work histories of the 20 affected employees revealed no common chemical exposures or work assignments, seven were maintenance workers, one boiler maker, one machinist and one operator in energy systems. All of these workers would be classified, according to our current ranking category, as being Risk Category C (possible electromagnetic field exposure).

In addition, Seidman et al. (17), in a study of brain tumor mortality among asbestos insulation workers in the United States and Canada, observed that the excess of brain tumors among insulators was concentrated in the younger ages (those under 50) and during the early period after onset of work (15-24 years) in contrast with the age distribution and latency in other asbestos-associated neoplasms. The authors concluded that "this may have relevance to theoretical concerns about questions of initiation and promotion in the etiology of cancer, particularly with regard to brain tumors". Since insulators or pipefitters frequently work in close proximity to electrical wiring, these occupation would also be ranked as

being Risk Category C in our study.

Bond et al. (18) conducted a case-control study of brain tumor deaths among employees at a large chemical manufacturing plant and found an association between risk of brain tumor and employment in a magnesium production department, particularly noted for the workers assigned to this department for a short period (1-5 years). Although the authors stated that some exposure to electromagnetic fields could be expected in both chlorine and magnesium production, they discounted this possibility because of a lack of other epidemiologic support and because the odds ratios tended to decrease with an increasing duration of employment in this department.

Another industry which utilizes high levels of electricity is aluminum production. Milham (19) found a significant increase of mortality from benign brain tumors (five observed versus 0.7 expected) among aluminum reduction plant workers, particularly for workers categorized as non-exposed to chemicals, such as mechanics, maintenance electrical, metal products, etc.

In a follow-up study of U.S. enlisted Naval personnel exposed to microwave radiation during the Korean War period (20), veterans were categorized as either high exposure (electronic technician, fire control technician or aviation electronics technician) or low exposure (radioman, radarman, and aviation electrician mate). No significant differences were noted in the rate of brain tumors between the two exposure groups. However, there were sixteen cases that died from malignancy of eye, brain and other nervous system (ICD Codes 190-192), representing 7.9 percent of all malignant deaths (16 out of 202) as compared with a 3.8 percent proportional mortality ratio of brain tumors to all malignancies among U.S. males, aged 20-64, in 1970 (21) ($P < 0.01$). Both groups of veterans were exposed

to electromagnetic fields and would be classified in Risk Category A or B in the current study. It is of interest to find that navy personnel were more represented among cases than controls in the present study (11 versus 4 in the glioma/astrocytoma group, and 8 versus 3 in the brain tumor non-specified group, see Table 4).

Wertheimer and Leeper (22) have reported that adults living in Colorado close to wires carrying high-flow alternating electric current have an increase in the incidence of all cancers. Cancer types most significantly associated with current wire configuration included cancer of the nervous system, uterus, breast and lymphoma. In addition, they observed that the strongest high current wire configuration-cancer association appears at periods after six to nine years exposure suggesting a rather short latency between alternating magnetic field exposure and cancer manifestation. In a similar study, they also found an association between electrical wire configuration and childhood cancer incidence (23). On the other hand, a study from Rhode Island did not show an association between childhood leukemia and electric wire configurations (24). A recent report from Sweden, however, is compatible with the study by Wertheimer and Leeper, showing an association between high tension wires and the occurrence of childhood tumors (25).

Several reports have already shown an increased risk of leukemia among electricians and other workers regularly exposed to electromagnetic fields (26-29).

Electrical and magnetic fields surround us, as they are emitted from high tension wires, radio transmitters, and household appliances. This

form of non-ionizing radiation extends from infrared to microwaves and radiowaves, and down to emissions from alternating electrical currents which have extremely low frequencies and long wave lengths. All except infrared rays readily penetrate the body; however, the amount of absorption varies depending on frequency of waves and type of tissue. Systems of the body which are particularly vulnerable to electromagnetic waves include the central nervous system, hematopoietic-immunologic system, cardiovascular and endocrine system (30).

The knowledge that pulsing electromagnetic fields can induce weak electric current in bone and stimulate osteogenesis has been well applied in the treatment of ununited fractures (31). Experimental studies on animals have also shown a proliferation reaction of the microglia in the brain (gliosis) following exposure to electromagnetic fields in various ranges of frequencies (32). Several investigators have reported the effects of electromagnetic fields on the efflux of calcium ion in biological system, principally brain tissue (33-35). Changes in calcium binding in chicken cerebral tissue have been demonstrated even with exposure to weak environmental electric fields oscillating at low frequency (33). Calcium ions play a prominent role in maintaining cellular membrane integrity and function. A large number of experimental observations suggest that a significant correlation may exist between the level of the electrical transmembrane potential difference in somatic cells and the intensity of their mitotic activity. Based on the experimental findings, Cone (36) has postulated a unified theory of mitosis control and oncogenesis associated with membrane potential difference. In fact, recent laboratory studies have demonstrated that weak pulsing electromagnetic fields can modify biological processes and induce RNA transcription (37).

Easterly (38) has hypothesized a mechanism for a relationship between exposure to magnetic fields and the induction of cancer: alternations in the mitotic processes caused by exposure to magnetic fields can provide a proliferative stimulus to latent tumor cells, thereby leading to the expression of malignant neoplasia. Wertheimer and Leeper (22) considered that their findings of a distinct pattern of latency between exposure to high current wires and cancer diagnosis in Colorado cancer cases is consistent with the hypothesis of cancer promotion produced by electromagnetic fields exposure. Our findings that glioma cases whose occupations more likely exposed them to electromagnetic fields developed and died from brain tumor at significantly younger ages compared with those who were not occupationally exposed to electromagnetic fields, also strongly support the theory of non-ionizing radiation as a promoting agent. The observation of Seidman and coworkers (17) that the excess of brain tumor among insulation workers was concentrated in the younger ages and during the early period after exposure can also be explained by this hypothesis. Furthermore, recent studies on experimental animals indicate that non-ionizing radiation may promote the development of several types of cancer, spontaneous or induced, in mice (39).

If oncogenic effects of non-ionizing radiation are limited only to the facilitation of the proliferation of tumor cells but not to the initiation of the malignant transformation of normal cells, then one may expect the promoting effects of electromagnetic fields exposure to be more apparent with respect to the mortality from certain types of tumor such as brain tumors and leukemia. These conditions usually result in death even without metastasis because of their vital location or incessant

proliferative capacity. Indeed, thus far epidemiologic evidence shows only the brain tumors and leukemia mortality to be associated with electromagnetic field exposure.

In recent decades there has been a rapid increase in the use of radiofrequency in industry, military and civilian settings. During the same period of time, the mortality rate for brain tumors in the United States also rose from 3.80 to 5.80 in whites and 2.15 to 3.85 in non-whites per 100,000 population for years from 1940 to 1977 (40). Although it is not known whether this reflects an actual increase in incidence of brain tumors or a difference in reporting and coding practices over time, if our data reflect a causal relationship between brain tumors and some characteristics of exposure to non-ionizing radiation, such a trend would be expected.

Despite this accumulation of epidemiologic evidence, the interpretation remains uncertain. It is not known whether the increased risk of brain tumors and leukemia among electrical workers is due to magnetic or electric fields themselves or possibly to a common chemical exposure such as polychlorinated biphenyls, other organic solvents, or metal fumes in these occupations.

If a causal association can be proved, the implications would be quite significant from the economic, social and political standpoint, as non-ionizing radiation is an important technology which permeates almost every aspect of life in modern, industrial society.

TABLE 1

Distribution of 951 white male brain tumor deaths in Maryland, 1969-1982, by type and ICD code, as recorded on death certificates

ICD Code	Glioma/Astrocytoma		Brain Tumor (Non-Specified)		Total	
	No.	%	No.	%	No.	%
191	388	74.7	129	29.8	517	54.3
192.9	127	24.5	0	0.0	127	13.4
225.0	0	0.0	2	0.5	2	0.2
238.1 or 239.6	4	0.8	301	69.7	305	32.1
Total	519	100.0	432	100.0	951	100.0

TABLE 2

Age distribution of 951 white male brain tumor deaths in Maryland, 1969-1982,
by type

Age	<u>Gliomas</u>		<u>Astrocytomas</u>		<u>Brain Tumors (Non-Specified)</u>	
	No.	%	No.	%	No.	%
20-29	11	3.0	5	3.4	10	2.3
30-39	25	6.8	14	9.4	28	6.5
40-49	63	17.0	24	16.1	57	13.2
50-59	98	26.5	37	24.8	102	23.6
60-69	116	31.3	55	36.9	129	29.9
70-79	44	11.9	12	8.1	84	19.4
80 & over	13	3.5	2	1.3	22	5.1
TOTAL	370	100.0	149	100.0	432	100.0
Mean Age (yrs.)	57.6		56.2		60.0	
S.D.	13.2		12.7		13.5	

TABLE 3

Observed number of electricity-related occupations among white male brain tumor deaths in Maryland, 1969-1982, as compared with the expected number from 1970 Maryland census data, by type

Occupation	1970 Maryland Census white male employees aged 20 and over		Glioma & Astrocytoma		Brain Tumor (Non-Specified)	
	No. of Employees	%	Obs. No.	Exp.* No.	Obs. No.	Exp.* No.
Electrician	9,300	1.15	13†	5.7	8	4.7
Electric or electronic Engineer technician	11,600	1.43	18†	7.2	12†	5.8
Utility (electric & telephone) lineman, serviceman	8,400	1.04	19†	5.1	8	4.2
3 occupations together	29,300	3.62	50†	18.0	28†	14.7
Total	809,600	100.0	499†	499.0	407†	407.0

* Expected number calculated according to 1970 census white male employee's occupation proportional distribution

† Excluded the number with unknown occupation

‡ P<0.01

TABLE 4

Occupation distribution between brain tumor cases and controls

Occupation	Glioma & Astrocytoma		Brain Tumor (Non-Specified)	
	No. of Cases	No. of Controls	No. of Cases	No. of Controls
Electrician	13	10	8	8
Electric or Electronic Engineer & Technician	18*	6	12	9
Utility Co. Employees	19	11	8	8
Carpenter	15	13	14	17
Mechanic, Machinist or Repairman	33	27	21	22
Petrochemical Ind.	5	4	7	6
High Professionals (physician, lawyer, etc.)	24	17	18	18
Farmer	14	12	15	9
Navy Personnel	11	4	8	3
Other Occupations	347	381	296	314
Unknown	20	34	25	18
Total	519	519	432	432

* $P < 0.05$

TABLE 6

Occupation distribution between primary brain tumor cases (glioma and astrocytoma) and controls, by category of electromagnetic field (E-M) exposure

Category of Occupation According to E-M Exposure	<u>Cases</u> No.	<u>Controls</u> No.	Odds Ratio	95% (Confidence) Intervals
A (Definite E-M Exposure)	27	14	2.15	(1.10-4.06)
B (Probable E-M Exposure)	21	12	1.95	(0.94-3.91)
C (Possible E-M Exposure)	128	99	1.44	(1.06-1.95)
D (No E-M Exposure)	323	360	1.00	
Unknown Occupation	20	34		
Total	519	519		

TABLE 5

Category of occupation according to assumed electromagnetic field (E-M) exposure:

Category A (Definite exposure to E-M field):

- (1) Electric and Telephone Company: Serviceman, lineman, foreman, and engineer;
- (2) Railroad and telecommunication: engineer;
- (3) Electrician, electric and electronic engineer in industry

Category B (Probable exposure to E-M field):

- (1) Electrician, non-specified, retail;
- (2) Dispatcher, highway patrolman;
- (3) Engineer (non-specified) in electric, electronic, aerospace and telecommunication industries;
- (4) Repairman in appliance (TV, radio, electronic device, etc.) and telecommunication industries;
- (5) Welder

Category C (Possible exposure to E-M field):

- (1) Policeman, security guard, airline pilot;
- (2) Employee (non-specified) in utility company (telephone and electric) railroad, and telecommunication industries;
- (3) Mechanic, machinist, repairman, maintenance man, stationary engineer, boiler, etc.;
- (4) Steelworker, tool maker, plumber, pipefitter, carpenter;
- (5) Engineer (non-specified) in other industries;
- (6) Officer (non-specified) in Navy, Air Force and Coast Guard

Category D (no exposure to E-M field):

All occupations other than the above stated 3 categories

TABLE 7

Occupation distribution between brain tumor cases (non-specified) and controls, by category of electromagnetic field (E-M) exposure

Category of Occupation According to E-M Exposure	<u>Cases</u> No.	<u>Controls</u> No.	Odds Ratio	95% (Confidence) Intervals
A (Definite E-M Exposure)	15	10	1.54	(0.68-3.38)
B (Probable E-M Exposure)	19	15	1.30	(0.60-2.78)
C (Possible E-M Exposure)	87	95	0.94	(0.68-1.31)
D (No E-M Exposure)	286	294	1.00	
Unknown Occupation	25	18		
Total	432	432		

TABLE 8

Mean age at death and standard deviation by category of E-M exposure and type

Category of E-M Exposure	<u>Glioma & Astrocytoma</u>		<u>Brain Tumor (Non-Specified)</u>	
	No. of Cases	Mean age at death $\pm$ SD	No. of Cases	Mean age at death $\pm$ SD
A (Definite E-M Exposure)	27	52.8 $\pm$ 11.1*	15	59.1 $\pm$ 17.2
B (Probable E-M Exposure)	21	61.2 $\pm$ 13.5	19	60.8 $\pm$ 11.1
C (Possible E-M Exposure)	128	56.2 $\pm$ 12.5	87	60.9 $\pm$ 13.1
D (No E-M Exposure)	323	57.9 $\pm$ 13.1	286	59.6 $\pm$ 13.6
Unknown Occupation	20	54.4 $\pm$ 16.9	25	61.5 $\pm$ 13.7
Total	519	57.2 $\pm$ 13.0	432	60.0 $\pm$ 13.5

* $P < 0.05$, as compared with no E-M exposure group age distribution

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