Brain Tumor Mortality Risk Among Men With Electrical and Electronics Jobs: A Case-Control Study [1]

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ABSTRACT—Brain tumor risk associated with electrical and electronics jobs and with occupational exposure to microwave and radiofrequency (MW/RF) electromagnetic radiation was evaluated with the use of data from a death certificate-based case-control study of brain tumors and occupational risk factors in northern New Jersey, Philadelphia, PA, and southern Louisiana. Next-of-kin of 435 white men who died of a primary brain tumor and of 386 controls who died from other causes were interviewed to obtain information on lifetime occupational history and other factors that might be related to excess brain tumor risk. The relative risk (RR) for all brain tumors was elevated among men exposed to MW/RF radiation [RR=1.6; 95% confidence interval (CI)=1.0, 2.4] and was significantly elevated among men exposed for 20 or more years. All of the excess risk for MW/RF radiation-exposed subjects was derived from jobs that involved the design, manufacture, repair, or installation of electrical or electronic equipment (RR=2.3; 95% CI=1.3, 4.2), while risk of brain tumors among MW/RF radiation-exposed subjects who never worked in electrical or electronics jobs was not elevated (RR=1.0; 95% CI=0.5, 1.9). Furthermore, risk was elevated for electronics workers who were considered to have no exposure to MW/RF radiation. Among electrical and electronics workers, risk was highest for engineers, teachers, technicians, repairers, and assemblers combined (RR=3.9; 95% CI=1.6, 9.9) and was limited to excess risk from astrocytic tumors (RR=4.6; 95% CI=1.9, 12.2). Risk of astrocytic tumors among these electronics manufacture and repair workers increased with duration of exposure to tenfold among those employed for 20 or more years. Among electricians and power and telephone linemen combined (electrical tradesmen), the RR for astrocytic tumors was slightly elevated, but not statistically significant (RR=1.8), and showed no consistent evidence of a duration-response relationship. Electrical tradesmen are exposed to extremely low frequency electromagnetic radiation, while men in some jobs associated with electronics manufacture and repair are exposed to electromagnetic radiation in the very high frequency and ultra-high frequency ranges and also may be exposed to soldering fumes, solvents, and a variety of other chemicals.—JNCI 1987; 79:233-238.

Two recent investigations suggested that individuals occupationally exposed to MW/RF electromagnetic radiation have an elevated risk of brain tumors (*1, 2*). In mortality surveys of occupations listed on death certificates, excess brain tumor deaths were observed among electrical engineers (*1, 3, 4*), electronics technicians (*2*), electricians (*1, 2, 5-7*), power station operators (*2*), and telegraph, telephone, and power linemen and servicemen (*1, 3*). Although these occupations might involve exposure to MW/RF radiation, some of them also might involve contact with lead, fumes from soldering, solvents, and a variety of other chemicals. These reports prompted an analysis of brain tumor mortality risk associated with MW/RF electromagnetic radiation exposure and with jobs involving electronics and electrical work using lifetime work histories obtained from next-of-kin in an investigation conducted in Louisiana, New Jersey, and Pennsylvania to study brain tumors in the petrochemical industry. Other occupational exposures considered in the present analyses were lead and soldering fumes.

SUBJECTS AND METHODS

Study population.—Cases and controls were selected from death certificates of usual residents of northern New Jersey; Philadelphia, PA, and surrounding counties; and the gulf coast of Louisiana. Cases were white men age 30 years or older who died of brain or other central nervous system tumors between January 1, 1979, and December 31, 1981 (January 1, 1978, and June 30, 1980, in Louisiana). Brain tumor diagnoses were verified through a hospital record review, and men whose underlying cause of death had been misclassified were elimi-

ABBREVIATIONS USED: CI=confidence interval; ELF=extremely low frequency; MW/RF=microwave and radiofrequency; RR=relative risk; SIC=Standard Industrial Classification; UHF=ultra-high frequency; VHF=very high frequency.

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nated from the case series. One control was selected for each case from men who died from causes other than brain tumor, epilepsy, stroke, suicide, or homicide and was matched to the case on age at death, year of death, and area of usual residence. Study subjects' next-of-kin were contacted and interviewed (response rate=70%; cases=74%; controls=63%) to obtain the following information on each job held by the study subjects since the age of 15: job title, brief job description, kind of company or organization, company name, job location (city, State), employment dates, and hours worked per week. Information on a number of possible brain tumor risk factors was also collected.

Exposure classification.—Each job entry in a study subject's work history was assigned a three-digit SIC code for industry (*8*) and a 1980 Census code for occupation (*9*). Two methods were used to classify subjects with respect to MW/RF radiation exposure. In an effort to be comparable to the earlier studies (*1, 2*), men who ever worked in the following occupations were considered exposed to MW/RF radiation (method 1): electronics and telecommunications engineers; electronics technicians and teachers; radio, radar, and telegraph operators; electricians; electrical linemen; electrical and electronics equipment repairmen; aluminum production workers; welders; and motion picture projectionists. These occupations were assigned the highest exposure classifications in the Maryland study (*1*) and were designated as exposed in the Washington study (*2*). In the present analyses, these MW/RF radiation-exposed jobs were divided into the following two categories according to their type of job: 1) those that involved MW/RF radiation exposure in the design, manufacture, installation, or maintenance of electronic or electrical equipment and 2) those that involved MW/RF radiation exposure in other types of jobs (e.g., welding and radio broadcasting).

Method 2 for classifying MW/RF radiation exposure was an independent step done by a certified industrial hygienist (P. A. S.) who assigned codes to each job listed in the lifetime occupational histories for presumed exposure to MW/RF radiation, lead (high, moderate, low), and soldering fumes (high, low). The method 1 and method 2 classifications for MW/RF radiation exposure overlapped considerably; however, method 2 included several supervisory jobs not considered exposed by method 1. Solder exposure occurred almost exclusively in electronics manufacture and repair jobs, i.e., electronics engineers, teachers, technicians, repairers, and assemblers. The lead exposure category consisted of a broad range of jobs, including those that involved exposure to lead in solders, gasoline, and paint.

Statistical analyses.—Information on 435 brain tumor cases and 386 controls was available for this investigation. In analyses by cell type, glioblastoma multiforme, astrocytoma, and mixed gliomas with astrocytic cells were grouped into one category because they arise from astrocytic cells and are thought to represent varying grades of the same tumorigenic process (*10*). A total of 300 cases were astrocytic tumors (astrocytoma, glioblastoma multiforme, or mixed glioma with astrocytic cells); 229 (76%) of these were histologically confirmed, and 71 were diagnosed by physicians as glioblastoma multiforme or astrocytoma based on appearance by computerized tomography. The remaining 135 were other ($n=90$) or unknown ($n=45$) cell types. Maximum likelihood estimates of the RR and 95% CIs (*11*) for brain tumors were calculated for each exposure and job category of interest and were adjusted for the potential confounding influences of educational level (highest number of years of school completed) in these data. An RR was considered statistically significant if the 95% CI did not include 1.0. Men who were never employed in any of the jobs that involved exposure to MW/RF radiation or to electrical and electronics equipment were considered "unexposed" in the analyses in tables 1-4. For the analyses of lead, solder, and MW/RF radiation exposure assigned by method 2, the unexposed were men who were classified by the industrial hygienist as never exposed to any of the three agents. Men who had jobs in the petroleum refining or petrochemical industry were not excluded from the unexposed referent because no excess brain tumor risk was associated with employment in these industries in this study.

RESULTS

Table 1 shows RR estimates for brain tumors among men classified as exposed to MW/RF radiation by method 1. Subjects who ever had a job associated with MW/RF radiation exposure had an RR of 1.6 for all brain tumors combined. However, the excess risk was limited to men who had worked in a job that involved the design, manufacture, installation, or maintenance of electronic or electrical equipment (RR=2.3). Men exposed to MW/RF radiation in other jobs (e.g., welding and radio broadcasting) did not have an elevated brain tumor risk. The overall excess risk came from a statisti-

TABLE 1.—*Brain tumor risk among study subjects ever exposed to MW/RF radiation*[a]

Exposure and/or occupation	Exposed cases	Exposed controls	RR[b]	95% CI
Ever exposed to MW/RF radiation	69	44	1.6	1.0, 2.4
Ever exposed to MW/RF radiation in an electrical or electronics job	44	19	2.3	1.3, 4.2
Exposed to MW/RF radiation but never worked in electrical or electronics job	25	25	1.0	0.5, 1.9

[a] The unexposed referent excludes subjects exposed to MW/RF radiation by method 1.
[b] Maximum likelihood estimate of the RR adjusted for educational class.

TABLE 2.—*Brain tumor risk among study subjects whose jobs ever involved exposure to MW/RF radiation by duration exposed*

Exposure and/or occupation	Total duration, in yr of MW/RF radiation exposure[a]			
	Unexposed[b]	<5	5–19	≥20
Ever exposed to MW/RF radiation				
Cases	359	18	18	29
Controls	341	17	8	15
RR[c]	1.0	1.0	2.3	2.0[d,e]
Ever exposed to MW/RF radiation in an electrical or electronics job				
Cases	359	8	11	22
Controls	341	8	3	7
RR[c]	1.0	1.1	3.7	3.1[d,e]
Exposed to MW/RF radiation but never worked in electrical or electronics job				
Cases	359	10	7	7
Controls	341	9	5	8
RR[c]	1.0	1.0	1.5	1.0

[a] "Exposed" subjects with unknown duration employed are excluded from these analyses.
[b] The unexposed referent excludes subjects exposed to MW/RF radiation by method 1.
[c] RR = maximum likelihood estimate of the RR adjusted for educational class.
[d] 95% CI does not include 1.0.
[e] Chi-square test for linear trend statistically significant at the .05 level.

cally significant twofold elevated brain tumor mortality among those exposed to MW/RF radiation for 5 or more years, although there was no consistent duration-response relationship with longer exposure (table 2). Once again, this overall excess was due to a threefold elevated risk among MW/RF radiation-exposed subjects who had an electrical or electronics job for 5 or more years (table 2).

The method 2 classification resulted in a similar finding for MW/RF radiation field exposure (RR=1.7; 95% CI=1.1, 2.7). When men who also had exposure to soldering fumes (primarily in electronics jobs) or lead were removed from the MW/RF radiation-"exposed" group, the RR for brain tumor mortality was 1.4 (95% CI=0.7, 3.1). Removing men who might have had occupational exposure to organic solvents from both the MW/RF radiation-exposed group and the unexposed referent further reduced the risk of brain tumors to 0.4 (2 cases; 5 controls).

Because excess brain tumor risk among MW/RF radiation-exposed men was restricted to those who held electronics and electrical jobs, these occupations were examined in more detail (table 3). There is overlap between the "exposed" subjects in table 3 and those in tables 1 and 2; however, electronics jobs not involving exposures to MW/RF radiation (e.g., assemblers) were also included in table 3. Electronics and electrical jobs were divided into the following two categories based on their potential exposures: 1) jobs associated with the manufacture and repair of electronics equipment, including engineers, teachers, technicians, repairers, and assemblers who could have exposure to VHF and UHF electromagnetic radiation and also to solvents and fumes from soldering (*12*); and 2) electrical trades jobs, including electricians, power linemen and servicemen, and telephone linemen and servicemen who would be exposed to ELF electromagnetic radiation (*12*). A statistically significant threefold excess risk of brain tumors occurred among men who had worked in jobs associated with the manufacture and repair of electronics. Brain tumor mortality risk estimates were elevated for each of the individual jobs included in this category: electrical engineers (cases=3; controls=1; RR=2.2; 95% CI=0.2, 55.8), electronics teachers (cases=4; controls=0), electronics technicians (cases=4; controls=1; RR=4.1; 95% CI=0.4, 96.3), electronics equipment repairers (cases=18; controls=4; RR=4.6; 95% CI=1.4, 16.4), and electronics assemblers (cases=6; controls=1; RR=5.6; 95% CI=0.7, 124.9). Some study subjects were counted more than once when the data were analyzed in this manner

TABLE 3.—*Brain tumor risk among study subjects ever employed in an electronics or electrical job*[a]

Occupation (Census codes)	All brain tumor cases	Exposed controls			Astrocytic tumor cases			Other brain tumor cases		
		No.	RR[b]	95% CI	No.	RR[b]	95% CI	No.	RR[b]	95% CI
Electronics manufacture and repair workers (055, 148, 213, 523-526, 528-533, 683)	28	7	3.9	1.6, 9.9	25	4.6	1.9, 12.2	3	1.4	0.3, 6.4
Electrical tradesmen (527, 575-577)	28	15	1.9	0.9, 3.8	18	1.8	0.8, 3.9	10	2.1	0.8, 5.2

[a] The unexposed referent excludes subjects exposed to MW/RF radiation by methods 1 and 2. Five cases and 2 controls had jobs in both occupation categories.
[b] RR = maximum likelihood estimate of the RR adjusted for educational class.

TABLE 4.—*Astrocytic tumor risk among study subjects ever employed in electronics or electrical jobs by duration employed*

Occupation (Census codes)	Duration employed, yr[a]			
	Unexposed[b]	<5	5-19	≥20
Electronics manufacture and repair workers (055, 148, 213, 523-526, 528-533, 683)				
Cases	246	10	6	8
Controls	341	4	1	1
RR[c]	1.0	3.3	7.6	10.4[d,e]
Electrical tradesmen (527, 575-577)				
Cases	246	7	3	6
Controls	341	6	4	4
RR[c]	1.0	1.6	1.0	2.6

[a] "Exposed" subjects with unknown duration employed are excluded from these analyses.
[b] The unexposed referent excludes subjects exposed to MW/RF radiation by methods 1 and 2.
[c] RR=maximum likelihood estimate of the RR adjusted for educational class.
[d] 95% CI does not include 1.0.
[e] Chi-square test for linear trend statistically significant at the .05 level.

because they held two or more of these jobs. The RR for mortality from all brain tumors among electrical tradesmen was 1.9 but was not statistically significant. For electricians alone, the RR was 1.4 (cases=17; controls=12; 95% CI=0.6, 3.3); for telephone linemen, it was 2.3 (cases=7; controls=3; 95% CI=0.5, 11.5). There were 4 cases but no controls who worked as power line installers.

Among men employed in electronics manufacture and repair jobs, the elevated risk for all brain tumors resulted primarily from a significant excess of mortality from astrocytic tumors. Of the 25 astrocytic tumors, 20 were histologically confirmed, while 2 of the 3 tumors included in the "other" category had unknown cell types. When the analyses were restricted to histologically confirmed astrocytic tumors, the RR was 4.9 (95% CI=1.9, 13.2). Electrical tradesmen did not have significantly elevated risks of astrocytic tumors, and the magnitude of the odds ratio for nonastrocytic tumors among electricians and power installers was similar to that for astrocytic tumors; however, 2 of the 10 cases in the "other" category had unknown brain tumor cell types, while 5 were unspecified gliomas.

Table 4 shows risk estimates for just astrocytic tumors by duration employed in an electronics or electrical job. Among men who ever worked in jobs associated with the manufacture and repair of electronics, risk of astrocytic tumors rose to tenfold after 20 years of employment. The risk of astrocytic tumors among electrical tradesmen showed no consistent pattern with increasing duration of employment.

The RR for mortality from astrocytic tumors among men exposed to soldering fumes in any job was 3.4 (95% CI=1.6, 7.5), but it did not vary considerably by presumed level of exposure. However, nearly all of the men exposed to soldering fumes had their exposure in electronics manufacture and repair jobs. Occupational exposure to lead was not associated with excess astrocytic tumor mortality either overall or by level of lead exposure (table 5). There was no risk gradient associated with duration of lead exposure.

DISCUSSION

The present analyses initially suggested an elevated risk of brain tumors among men with occupational exposure to MW/RF electromagnetic radiation that was due to an excess mortality among those exposed for 5 or more years. However, men who had MW/RF radiation exposure in jobs not involving electronic and electrical equipment design, manufacture, installation, or maintenance did not have an excess brain tumor risk. In addition, assemblers, who held electronics jobs but were presumably not exposed to MW/RF radiation, experienced

TABLE 5.—*Astrocytic tumor risk among study subjects ever occupationally exposed to lead*[a]

Exposure	Exposed cases	Exposed controls	RR[b]	95% CI
Ever exposed to lead	91	118	1.1	0.8, 1.6
Presumed level of lead exposure[c]				
Low	55	64	1.2	0.8, 1.9
Moderate	7	6	2.0	0.6, 6.9
High	29	48	0.9	0.5, 1.5

[a] The unexposed referent for each of these analyses excludes study subjects who ever worked in jobs that involved exposure to MW/RF radiation or soldering fumes.
[b] RR = maximum likelihood estimate of the RR adjusted for educational class.
[c] The low category includes subjects who had one or more jobs classified as low, but never had a job classified in the medium or high category; the medium category includes subjects who had one or more jobs classified as medium, but never had a job classified as high; the high category includes subjects who ever had a job classified as high.

excess brain tumor risk. Elevated brain tumor mortality appeared to be due primarily to excess astrocytic tumor risk, which increased by duration employed in electronics manufacture and repair jobs. Results of the present study are consistent with those of earlier studies that found excess brain tumor risk among men in electronics jobs (*1-4*). Studies of electronics workers in Sweden did not find elevated risk for brain tumors (*13-15*).

The pattern of excess brain tumor risk among electrical and electronics workers, and not among others exposed to MW/RF radiation, suggests that simple exposure to MW/RF radiation is not the responsible agent. Modifying factors might include the type of MW/RF radiation or the presence of other exposures. Electrical tradesmen are exposed to ELF radiofrequencies associated with electric power lines, while some electronics manufacture and repair workers are exposed to UHF and VHF frequencies (*12*). However, MW/RF radiation exposure in electronics jobs is probably intermittent and may be accompanied by exposures to lead, solder fluxes, solvents, and other chemicals.

Solders used in the electronics industry are usually a combination of lead and tin, but they may also contain cadmium or zinc (*12, 16*). The most common solder flux, the coating around the soldering wire, is pine resin (colophony), which is associated with occupational asthma (*16*). When colophony is heated, by-products include aliphatic aldehydes like formaldehyde (*16*) and many other substances. Fluoride compounds are also used as solder fluxes (*16*). Lead is known to be neurotoxic (*17*), but its role as a carcinogen is questionable. Several laboratory studies have produced renal tumors in rodents exposed to inorganic lead (*18*), and gliomas were induced in rats fed a diet of lead subacetate (*19*). A case report described 2 children who showed clinical symptoms of lead poisoning and subsequently developed astrocytomas (*20*). However, numerous studies have been conducted of workers exposed to lead in battery plants and smelters, and none have indicated an excess risk of brain cancer (*18, 21-25*). Our data showed an elevated brain tumor mortality risk among men occupationally exposed to soldering fumes, but almost all of the "exposed" were electronics workers; thus the effects of soldering fumes could not be evaluated separately from solvents, MW/RF radiation, and other exposures associated with these jobs. There was no increased brain tumor mortality risk among men who presumably had occupational exposure to lead.

Numerous solvents including 1,1,1-trichloroethane (methylchloroform), trichloroethylene, tetrachloroethylene, and methyl ethyl ketone (*16*) used throughout the electrical and electronics industry are known neurotoxins, causing peripheral neuropathy, central nervous system depression, and neurobehavioral dysfunction (*17*). A common acute effect of exposure to halogenated hydrocarbon solvents like methylchloroform, trichloroethylene, and tetrachloroethylene is anesthesia (*17*). Experimental studies have shown that trichloroethylene and tetrachloroethylene cause liver tumors in animals (*17, 26*), suggesting that they could be carcinogenic in humans. There have been insufficient experimental data to evaluate the carcinogenicity of methylchloroform (*26, 27*); however, a recent study reported evidence of astrogliosis in gerbils exposed to methylchloroform by inhalation (*28*).

In summary, our data suggest that certain jobs involving the design, manufacture, installation, or maintenance of electronics or electrical equipment involve exposures that are related to excess risk of astrocytic brain tumors. Because these jobs may involve a wide variety of exposures (*16*), a specific etiologic agent cannot be identified from the present data. Results should be interpreted with some degree of caution, because when risks were calculated for specific occupations and for individual strata by duration employed, numbers in single cells were very small; therefore, the magnitude of some RR estimates may be overstated or understated by these analyses. Despite this limitation, our findings suggest that further investigations of electronics jobs should be conducted, with particular attention to exposures to MW/RF radiation, soldering fumes, and solvents.

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