Occupational Exposure to 60-Hertz Magnetic Fields and Risk of Breast Cancer in Women

Patricia F. Coogan,[1] Richard W. Clapp,[1] Polly A. Newcomb,[2] Thurman B. Wenzl,[3] Greg Bogdan,[4] Robert Mittendorf,[5] John A. Baron,[6] and Matthew P. Longnecker[7]

We used data from a large population-based case-control study to test the hypothesis that women whose "usual occupation" entailed exposure to higher than background 60-Hz magnetic fields had a higher risk of breast cancer than women without such exposure. Breast cancer cases were identified from four statewide tumor registries, and controls were randomly selected from lists of licensed drivers and Medicare beneficiaries. Information on usual occupation and breast cancer risk factors was obtained by telephone interview. We calculated adjusted odds ratios from logistic regression models for women holding occupations with potential for low, medium, or high magnetic field exposure, compared with background exposure. There was a modest increase in risk for women with potential for high exposure [odds ratio (OR) = 1.43; 95% confidence interval (CI) = 0.99–2.09], and no increase for women with potential for medium (OR = 1.09; 95% CI = 0.83–1.42) or low (OR = 1.02; 95% CI = 0.91–1.15) exposure. The risk among premenopausal women in the highest-exposure category was higher (OR = 1.98; 95% CI = 1.04–3.78) than for postmenopausal women (OR = 1.33; 95% CI = 0.82–2.17). (Epidemiology 1996;7:459–464)

Keywords: electromagnetic fields, breast neoplasms, occupational exposure, case-control studies, menopause.

Breast cancer was first associated with exposure to power frequency (50- or 60-Hz) magnetic fields in 1990–1991, when three reports of excess breast cancer in male electrical workers were published.[1–3] These reports were followed by four studies in men that offered little support for the association.[4–7] Analyses of occupational exposure and female breast cancer mortality by Loomis *et al*[8] and Cantor *et al*[9] on the same dataset yielded conflicting interpretations. Nevertheless, interest has continued in the subject, in part because a biological mechanism has been proposed.[10,11] In some species, exposure to magnetic fields inhibits the nightly synthesis of melatonin by the pineal gland.[12] This, in turn, may result in higher levels of circulating estrogens, which could increase proliferation of breast stem cells.[10] In addition, melatonin inhibits breast cancer cell proliferation *in vitro*,[13] an effect blocked by 60-Hz magnetic fields.[14] Whether magnetic fields inhibit melatonin synthesis in humans, or influence breast tumor development in women, remains to be shown.[15,16]

In the present report, we have used data from a large population-based case-control study[17,18] to investigate the association between occupations with potential for exposure to 60-Hz magnetic fields and the incidence of female breast cancer. Extensive information on breast cancer risk factors allowed us to adjust risk estimates for known potential confounders.

Methods

SELECTION OF CASES AND CONTROLS

Female residents of Maine, Wisconsin, Massachusetts, and New Hampshire who were 74 years of age or younger, and who were reported to the state cancer registry with a newly diagnosed case of breast cancer between April 1988 and December 1991, were eligible for the study. New Hampshire subjects were enrolled beginning in January 1990. Registry case ascertainment rates are 95% in Massachusetts and Wisconsin and 90% in Maine and New Hampshire.[19,20] Cases without a listed telephone number, or (if less than 65 years) without a driver's license, were excluded.

Controls less than 65 years old were randomly selected from state driver's license lists, and those 65–74 years old were randomly chosen from the Health Care

From the [1]Department of Environmental Health, Boston University School of Public Health, Boston, MA; [2]Comprehensive Cancer Center, University of Wisconsin, Madison, WI; [3]National Institute for Occupational Safety and Health, Cincinnati, OH; [4]Maine Bureau of Health, Augusta, ME; [5]Department of Obstetrics and Gynecology, Pritzker School of Medicine, University of Chicago, Chicago, IL; [6]Departments of Medicine and Family and Community Medicine, Dartmouth Medical School, Hanover, NH; and [7]Epidemiology Branch, National Institute of Environmental Health Sciences, Research Triangle Park, NC.

Address reprint requests to: Patricia F. Coogan, Department of Epidemiology and Biostatistics, Boston University School of Public Health, 80 E. Concord Street, Boston, MA 02118.

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TABLE 1. Occupations That Occur in the Study Population Categorized by Exposure to 60-Hz Magnetic Fields above Background Levels and Their Classification in Three Other Exposure Schemes

Occupation	Loomis *et al*[8]*	Lin *et al*[21]†	Milham[22]‡
High potential for exposure			
Electrical/electronic engineers (055)§	1	A	
Computer system analysts/scientists (064)			
Electrical/electronic technicians (213)	1	A	1
Computer equipment operators (308–309)	2		1
Electronic/data processing equipment repairers (523, 525)	1	B	1
Electrical/electronic equipment assemblers (683)			
Medium potential for exposure			
Other engineers (044–054, 056–063)		B, C	
Statisticians and scientists (065–078)			
Engineering technicians (214–216)			
Computer programmers (229)	2		
Billing, posting, and calculating machine operators (344)			
Communications equipment operators, nec‖ (306, 348–353)	2		1
Electrical equipment repairers (526–534)	1		1
Electricians (555, 575–576)	1	A	2
Machinists/tool and die makers (634–639)		C	
Precision inspectors, testers, and related workers (689, 693)			
Welders and cutters (783)		B	2
Low potential for exposure			
Accountants, underwriters, other financial officers (689, 693)			
Health diagnosing occupations (084–089)			
Pharmacists (096)			
Librarians (164)			
Social scientists/urban planners (166–173)			
Authors and technical writers (183, 184)			
Hotel clerks/transportation ticket agents (317, 318)			
Bookkeepers/financial clerks (337–343)			
Office machine and communications equipment operators (345–347)			
Data entry keyers and statistical clerks (385, 386)	2		
Elevator operators (454)			
Industrial machinery repairers and maintenance workers (518, 519)		C	
Misc. mechanics and repairers (538–549)		C	
Dressmakers and tailors (666, 667)			
Shoe repairers and apparel patternmakers (669, 673)			
Optical goods, dental laboratory, medical appliance technicians (677, 678)			
Metalworking machine operators (703–705, 708–709)			
Heat-treating equipment, furnace, kiln, and oven operators (724, 766)			
Woodworking, textile, and shoe machine operators (726–728, 744–745)			
Printing machine operators (734, 736, 737)			
Slicing and cutting machine operators (769)			
Production inspectors, testers, and samplers (796–798)			
Operating engineers (844)			
Background exposure			
All other occupations			

* 2-category scheme: 1 = "electrical occupations"; 2 = "other occupations with potential exposure."
† 3-category scheme: A = "definite exposure"; B = "probable exposure"; C = "possible exposure."
‡ 2-category scheme: 1 = "electromagnetic field exposure"; 2 = "electromagnetic field exposure and other exposure."
§ Bureau of Census codes in parentheses.
‖ nec = not elsewhere classified.

Financing Administration's list of Medicare beneficiaries. Computer files of potential controls from both sources were obtained annually. Controls were required to have no history of breast cancer and to have a listed telephone number. In each state, the controls were frequency matched by 5-year age intervals to the cases. Detailed methods of this study have been described previously.[17,18]

Of all reported cases, 22% had no phone number available, 3% had no driver's license, and 3% were ineligible for other reasons (prior breast cancer, did not speak English, or were missing information on eligibility). Of 8,532 eligible cases, physicians refused contact for 710 (8.3%), 463 (5.4%) had died, 66 (0.8%) could not be located, and 405 (4.7%) refused to be interviewed. Of all potential controls, 27% had no phone number available, less than 1% had no driver's license, and 3% were ineligible for other reasons. Of 11,329 eligible controls, 126 (1.1%) had died, 153 (1.2%) could not be located, and 1,521 (13.3%) refused to be interviewed. The overall participation rates were 81% for cases and 84% for controls, with a final study population of 6,888 cases and 9,529 controls.

Information Collected at Interview

A 25-minute telephone interview obtained information on usual occupation, asked in one question: "What job is most representative of your occupation during your lifetime?" If the occupation was not clear, the subject was asked: "What duties did that job involve?" and "What industry was this job in?" Information was also obtained on reproductive history and other breast cancer risk factors. Subjects were requested not to discuss their medical history until the end of the interview. Interviewers were not aware of subject disease status until the end of the interview for 74% of the cases and 90% of the controls.

Exposure Classification

Usual occupation and industry were coded according to 1980 Bureau of the Census 3-digit occupation codes. We translated the codes into three categories with potential for exposure to 60-Hz magnetic fields above background levels (low, medium, and high). We aggregated all other occupations into a single reference group called "background." An industrial hygienist (T. B. W.) developed the exposure scheme. Occupational coding and exposure classification were done blindly as to subject case status.

TABLE 2. Odds Ratios (OR) and 95% Confidence Intervals (CI) for 3 Categories of Exposure to 60-Hz Magnetic Fields

Potential for Exposure	Cases	Controls	Simple OR*	95% CI	Multivariate OR†	95% CI
Background	6,113	8,454	1.00	Referent	1.00	Referent
Low	577	813	1.05	0.93–1.18	1.02	0.91–1.15
Medium	104	143	1.10	0.85–1.43	1.09	0.83–1.42
High	57	65	1.42	0.98–2.05	1.43	0.99–2.09

* Adjusted for age and state. *P*-value for trend = 0.06.
† Adjusted for age, state, body mass index (weight in kg/height in m^2) (<21.5, 21.5–23.8, 23.9–26.7, >26.7, missing), benign breast disease (yes, no, unknown), family history of breast cancer (yes, no, unknown), menopausal status (pre-, post-, unknown), age (years) at menarche (<11, 11–12, 13–14, ≥15, missing), parity (nulliparous, 1, 2, 3, ≥4, missing), age (years) at first birth (<20, 20–24, 25–29, ≥30, missing), education (< high school, high school graduate, some college, college graduate, missing), and alcohol consumption (gm/day) (≤4.75, 4.76–19.6, 19.7–60.4, >60.4, missing). *P*-value for trend = 0.11.

Occupations in this study population with potential for exposure above background are listed in Table 1. Magnetic fields are generated by flowing electrical current, especially in multiple coils of wire, so typical sources include small motors, fluorescent light ballasts, and cathode ray tube displays. Since magnetic fields fall off rapidly with distance, close proximity to the source is necessary for elevated exposure to occur.

We ranked occupations based on three considerations: (1) strength of the potential magnetic field source, (2) proximity of work station to the source, and (3) how frequently a worker is at the work station proximate to the source. Overall, this scheme is similar, but not identical, to those used in previous studies of occupational exposure to magnetic fields (Table 1).[8,21,22] Most occupations in the high- and medium-exposure categories are considered exposed by other authors. The low-exposure category, however, includes occupations that were not considered exposed by other authors.

Statistical Analysis

We used conditional logistic models stratified on age and state to accommodate the different age distribution of the cases and controls in each state.[23] Odds ratios adjusted for age and state (the matching variables) were estimated for the three categories of exposure compared with the background group. We evaluated trend in the relative risks by including the exposure level as a single ordinal variable in the models. In the conditional logistic regression analyses, we controlled for potential confounding by family history of breast cancer, alcohol consumption, body mass index, menopausal status, education, history of benign breast disease, age at menarche, parity, and age at first birth. We specified each variable with a series of indicator variables, including a category for subjects with missing data.

We determined menopausal status on the basis of history of natural menopause or bilateral oophorectomy. We classified women with a hysterectomy who had a least one remaining ovary as premenopausal if the reference age was in the first decile of age at natural menopause, as postmenopausal if this age was the highest decile of age at natural menopause, or as menopausal status unknown if the age was intermediate. Deciles of age at natural menopause (12 months without menses) were smoking status specific.[17,18]

Results

The majority of the study population was white (98.4%). Most subjects were from Wisconsin (3,789 cases, 3,999 controls) followed by Massachusetts (1,847 cases, 3,050 controls), Maine (699 cases, 1,559 controls), and New Hampshire (553 cases, 921 controls). Fifty seven per cent of cases (N = 3,902) and 51% of controls (N = 4,845) were over 60 years old, and 86% of cases (N = 5,880) and 87% of controls (N = 8,216) had borne at least one child. Established breast cancer risk factors showed associations of the expected magnitude and direction, as have been described elsewhere.[17]

Seventy six per cent of cases (N = 5,223) and 76% of controls (N = 7,236) reported a usual occupation outside the home. Twenty three per cent of cases and of controls reported their usual occupation as housewife (1,612 cases, 2,219 controls), and less than 1% (16 cases, 20 controls) reported that they were volunteers, students, or never worked owing to disability. Ninety-one subjects (37 cases and 54 controls) were missing codable occupational information.

Relative to women with background exposure only, a 43% increase in breast cancer risk was present in the highest-exposure category [odds ratio (OR) = 1.43; 95% confidence interval (CI) = 0.99–2.09] (Table 2). The relative risks for the medium- (OR = 1.09; 95% CI = 0.83–1.42) and low- (OR = 1.02; 95% CI = 0.91- 1.15) exposure categories did not differ appreciably from unity. The multivariate adjusted relative risks for the three categories differed only slightly from those adjusted for age and state alone (Table 2).

The reference group (background exposure) to which exposed subjects were compared included all subjects, whether they worked outside the home or not. We repeated the analyses after excluding women who reported their usual occupation as housewife, student, or volunteer, or who never worked owing to disability (1,628 cases, 2,241 controls), and the relative risks were essentially identical to those shown in Table 2 (data not shown). Likewise, when we excluded subjects reporting occupations with potential exposure to ionizing radiation (41 cases, 65 controls), the relative risks did not change appreciably.

Premenopausal women in the highest-exposure group had twice the estimated risk of breast cancer as those in the background group (OR = 1.98; 95% CI = 1.04–

TABLE 3. Odds Ratios (OR) and 95% Confidence Intervals (CI) for 3 Categories of Exposure to 60-Hz Magnetic Fields by Menopausal Status

Potential for Exposure	Cases	Controls	Simple OR*	95% CI	Multivariate OR†	95% CI
Premenopausal						
Background	1,295	2,414	1.00	Referent	1.00	Referent
Low	91	198	0.93	0.71–1.22	0.91	0.69–1.20
Medium	18	39	0.80	0.45–1.43	0.82	0.45–1.47
High	20	24	1.84	0.98–3.44	1.98	1.04–3.78
Postmenopausal						
Background	4,588	5,692	1.00	Referent	1.00	Referent
Low	462	592	1.04	0.91–1.19	1.01	0.89–1.16
Medium	78	100	1.14	0.84–1.55	1.10	0.80–1.50
High	35	37	1.32	0.81–2.13	1.33	0.82–2.17

* Adjusted for age and state (the matching variables). *P*-value for trend = 0.54 (premenopausal), 0.17 (postmenopausal).
† Adjusted for age, state, body mass index (weight in kg/height in m^2) (<21.5, 21.5–23.8, 23.9–26.7, >26.7, missing), benign breast disease (yes, no, unknown), family history of breast cancer (yes, no, unknown), age (years) at menarche (<11, 11–12, 13–14, ≥15, missing), parity (nulliparous, 1, 2, 3, ≥4, missing), age (years) at first birth (<20, 20–24, 25–29, ≥30, missing), education (< high school, high school graduate, some college, college graduate, missing), and alcohol consumption (gm/day) (≤4.75, 4.76–19.6, 19.7–60.4, >60.4, missing). *P*-value for trend = 0.49 (premenopausal), 0.30 (postmenopausal).

3.78) (Table 3). Relative risks were below unity for the medium- (OR = 0.82; 95% CI = 0.45–1.47) and low- (OR = 0.91; 95% CI = 0.69–1.20) exposure categories. Among postmenopausal women in the highest-exposure category, the relative risk was only slightly elevated (OR = 1.33; 95% CI = 0.82–2.17), and relative risks were essentially unity for the medium- (OR = 1.10; 95% CI = 0.80–1.50) and low- (OR = 1.01; 95% CI = 0.89–1.16) exposure categories. Multivariate adjustment changed the simple relative risks only slightly (Table 3). The *P*-value for the interaction term combining menopausal status and exposure was 0.46.

For specific occupations in the high- and medium-exposure categories, we calculated relative risks if there were at least 10 subjects (Table 4). In the highest-exposure category, computer equipment (mainframe) operators had an elevated relative risk of 1.79 (95% CI = 1.03–3.11), whereas the relative risk for electric/electronic equipment assemblers was not appreciably elevated. In the medium-exposure category, no occupations had strongly elevated relative risks except "precision inspectors, testers, and related workers" (OR = 7.99; 95% CI = 1.69–37.84), but this estimate was based on only 9 cases and 2 controls. Engineering technician and computer programmers had unstable relative risks less than unity.

Discussion

In this large case-control study, women who reported a usual occupation with potential for high exposure to 60-Hz magnetic fields had a 43% increased risk of breast cancer, compared with women with background exposure. Relative risks for the medium- and low-exposure categories were not substantially elevated. Premenopausal women in the highest-exposure category had a twofold elevated relative risk.

An association between breast cancer mortality and residential exposure estimated from wiring configurations was reported among women in Denver,[24] but not in two European studies.[25,26] In a study of electric blanket use, there were slight risk increases in premenopausal (OR = 1.43; 95% CI = 0.94–2.17)[27] and postmenopausal (OR = 1.46; 95% CI = 0.96–2.20)[28] women who used them throughout the night, but the association was diminished when a more restricted definition of high use was used.

Two Scandinavian cohorts with possible occupational exposure to magnetic fields had slight deficits of female breast cancer mortality[29] and incidence.[4] In the United States, an analysis of death certificate data found a 38% (95% CI = 1.04–1.82) relative increase in proportional breast cancer mortality among woman who held electrical occupations.[8] A similar analysis of the same database augmented by an additional year of data and using different exposure definitions, however, concluded that there was no association.[9] The earlier study reported a slight deficit of breast cancer risk for computer equipment operators (Bureau of the Census code 308) (OR = 0.88; 95% CI = 0.70–1.10), based on 99 cases and 354 controls, which conflicts with our finding of an increased risk for this occupation.

The similarity of the simple and multivariate risk estimates indicates that breast cancer risk factors included in the multivariate model do not meaningfully confound the association. Although some unknown risk factor that occurs in occupations with potential for high exposure may have caused the observed effects, exposed occupations do not share exposures to agents known or suspected to cause breast cancer.[8] Despite the large study population and high response rates, few women were in the highest-exposure group or in specific occupations of interest. Consequently, our relative risk estimates are somewhat imprecise, and we cannot exclude chance as an explanation for the observed risk increases.

A major limitation of this study is misclassification of exposure. Exposure is based on one occupational code, based on the subject's response to a question about "most representative" occupation. Since all subjects were interviewed, the responses are an improvement over occupations coded from death certificates used in other studies.[8,9] A more fundamental issue, however, is how accurately exposure categories reflect exposure to mag-

TABLE 4. Odds Ratios (OR) and 95% Confidence Intervals (CI) for Specific Occupations in High- and Medium-Exposure Categories with at Least 10 Subjects

Occupation	Cases	Controls	Simple OR*	95% CI	Multivariate OR†,‡	95% CI
High potential for exposure						
Computer equipment operators (308)	31	26	1.80	1.04–3.12	1.79	1.03–3.11
Electric/electronic equipment assemblers (683)	20	27	1.19	0.66–2.14	1.20	0.66–2.18
Medium potential for exposure						
Other engineers (44–54, 56–63)	4	6	1.18	0.33–4.26		
Welders and cutters (783)	6	6	1.28	0.41–4.05		
Communications equipment operators (306, 348–353)	57	74	1.15	0.80–1.64	1.13	0.79–1.63
Machinists, tool and die makers (634–639)	6	4	1.67	0.45–6.17		
Statisticians and scientists (65–78)	12	15	1.22	0.55–2.7	1.22	0.54–2.75
Precision inspectors, testers, and related workers (689, 693)	9	2	7.99	1.69–37.84		
Engineering technicians (214–216)	4	12	0.67	0.21–2.15		
Computer programmers (229)	3	10	0.43	0.12–1.59		

* Reference group for all ORs is background exposure group. Adjusted for age and state.

† Adjusted for age, state, body mass index (weight in kg/height in m²) (<21.5, 21.5–23.8, 23.9–26.7, >26.7, missing), benign breast disease (yes, no, unknown), family history of breast cancer (yes, no, unknown), menopausal status (pre-, post-, unknown), age (years) at menarche (<11, 11–12, 13–14, ≥15, missing), parity (nulliparous, 1, 2, 3, ≥4, missing), age (years) at first birth (<20, 20–24, 25–29, ≥30, missing), education (< high school, high school graduate, some college, college graduate, missing), and alcohol consumption (gm/day) (≤4.75, 4.76–19.6, 19.7–60.4, >60.4, missing).

‡ Multivariate ORs calculated only when there were at least 25 subjects.

netic fields.[16] Although workers in electrical occupations have higher exposures to magnetic fields than nonelectrical workers,[7,30,31] there is considerable variation in exposure between occupations included in the same aggregate exposure category, and also within the same occupation.[7,31]

Other sources of misclassification include lack of information on jobs missed by the "usual occupation" response and on the duration and timing of exposure. In this group of older women, an occupation reported as "usual" may have been a job held for a short time. The occupation may have had high exposure, but the actual accrued exposure could be minimal. Such misclassification may have diluted the association in postmenopausal women, compared with premenopausal women. Or, the smaller effect in postmenopausal women may indicate that the different estrogen environments in pre- and postmenopausal women may modulate an effect of magnetic fields, if any.

Finally, we lacked information on nonoccupational sources of exposure. The major source of domestic exposure to magnetic fields is related to the power distribution network and the use of appliances.[32] Our analysis assumes that occupational exposure to magnetic fields in jobs with elevated exposure consistently exceeds nonoccupational exposure. Data support this assumption in the electric utility industry[30,33] and in a number of other exposed occupations.[34]

Although misclassification of exposure status is the major limitation of this study, it was likely to have been nondifferential and thus to have underestimated, rather than overestimated, the true risk.[35]

Overall, these data indicate that there may be a modest association between occupational exposure to magnetic fields and risk of breast cancer in women. The question remains whether the excess risks in these data reflect exposure to magnetic fields, some other, unidentified characteristic of women in these occupations, or random variation.

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