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Original Contribution

Occupational Exposure to Magnetic Fields and Breast Cancer Among Women Textile Workers in Shanghai, China

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Exposure to magnetic fields (MFs) is hypothesized to increase the risk of breast cancer by reducing production of melatonin by the pineal gland. A nested case-cohort study was conducted to investigate the association between occupational exposure to MFs and the risk of breast cancer within a cohort of 267,400 female textile workers in Shanghai, China. The study included 1,687 incident breast cancer cases diagnosed from 1989 to 2000 and 4,702 noncases selected from the cohort. Subjects' complete work histories were linked to a job–exposure matrix developed specifically for the present study to estimate cumulative MF exposure. Hazard ratios and 95% confidence intervals were calculated using Cox proportional hazards modeling that was adapted for the case-cohort design. Hazard ratios were estimated in relation to cumulative exposure during a woman's entire working years. No association was observed between cumulative exposure to MFs and overall risk of breast cancer. The hazard ratio for the highest compared with the lowest quartile of cumulative exposure was 1.03 (95% confidence interval: 0.87, 1.21). Similar null findings were observed when exposures were lagged and stratified by age at breast cancer diagnosis. The findings do not support the hypothesis that MF exposure increases the risk of breast cancer.

breast cancer; electric and magnetic fields; occupation; textile industry

Abbreviations: IARC, International Agency for Research on Cancer; MF, magnetic fields; STIB, Shanghai Textile Industry Bureau.

***Editor's note:** An invited commentary on this article appears on page 1046.*

Breast cancer is the most frequent nonskin cancer in women worldwide (1). Although there has been intensive research to improve the understanding of the biology of breast cancer, the etiology of breast cancer remains poorly understood. The contributions of occupational factors to the risk of breast cancer have not been adequately studied, especially in view of the large number of women in the workforce worldwide who face potentially hazardous exposures. Magnetic fields (MFs) from the production, distribution, and use of electricity are a widespread occupational exposure that is increasing throughout the world. MF exposure is hypothesized to increase the risk of breast cancer primarily by reducing production of melatonin by the pineal gland, which could alter the risk of breast cancer through its regulation of reproductive hormones by influencing the hypothalamic-pituitary-gonadal axis. Decreased concentrations of circulating melatonin can result in increased releases of gonadotrophins by the pituitary gland and increased levels of ovarian hormone production by the ovaries, thus potentially increasing risk of breast cancer (2). In 2002, on the basis of evidence that suggested that high levels of residential exposure are associated with an increased risk of childhood leukemia, the International Agency for Research on Cancer (IARC) concluded that extremely low-frequency MFs are possibly carcinogenic to humans. Evidence that MFs alter the risk of breast cancer was considered inadequate (3). Subsequent to IARC's evaluation, a considerable amount of epidemiologic research has been devoted to understanding the potential relationship between MF exposure and the risk of breast cancer. In 2007, the World Health Organization Environmental Health Criteria Programme reviewed the data concerning the risk of breast cancer associated with MF exposure that was published after the IARC monograph and determined that the IARC conclusions remain the same, as the new evidence did not support an association between MF exposure and breast cancer (4). However, the updated evidence that was reviewed by World Health Organization Environmental Health Criteria Programme was mostly research on residential MF exposures and breast cancer. Studies on occupational exposures to MFs were limited. The aim of the present study was to investigate the potential association of breast cancer risk with occupational MF exposure in a well-characterized cohort of over 267,000 female workers in the Shanghai textile industry.

MATERIALS AND METHODS

Study population and case finding

The present study was an extension of a series of case-cohort studies of exposures to dusts, chemicals, and other physical agents in the Shanghai textile industry. Details of the study design and case identification have been described previously (5–7). Briefly, the previous studies were based in a cohort of 267,400 workers from 503 textile factories in the Shanghai Textile Industry Bureau (STIB) who were recruited in 1989–1991 into a randomized trial of the association of breast self-examination with breast cancer mortality (8, 9). The cohort consisted of active and retired female employees who were permanent residents of Shanghai born between January 1, 1925, and December 31, 1958. At enrollment into the trial, women were administered a baseline questionnaire that elicited information on demographic variables, lifestyle habits, reproductive history, and other putative risk factors for breast cancer.

Follow-up of the cohort has been described previously (9). Incident breast cancer cases were identified from January 1989 through July 2000 using frequent periodic reviews of the records of the medical clinic in each factory and annual medical reports submitted by the factory clinics to a cancer and death registry maintained by the Station for the Prevention and Treatment of Cancer of the STIB. Incidence data were supplemented with manual reviews of records from the Shanghai Cancer Registry and a computerized matching of members of the trial cohort to that registry's database. The diagnoses of all incident breast cancer cases were verified by review of pathology reports or examination of histologic slides by a reference pathologist as part of the trial. In all, 1,763 breast cancer cases were identified, among whom 99% had diagnoses that were histologically confirmed.

The comparison group (or noncases) included 4,780 women from 2 data sources. The first was 3,153 breast cancer–free women who had been randomly selected as a reference subcohort for a series of nested case-cohort analyses. The subcohort was selected to match the year-of-birth distribution of all cancer cases, among whom women with breast cancer comprised the largest group (7). The second was 1,627 women who had served as age-matched controls in 2 previous nested case-control studies of breast cancer in relation to nutritional factors (10) and induced abortion (11). Adding controls with a similar age distribution to the original subcohort was done to increase statistical power.

Exposure assessment

Jobs in the Shanghai textile industry included the manufacture of fibers, cloth, and ancillary products, garment assembly, and textile machine manufacture and repair. Many jobs involved working with or in proximity to machinery (e.g., sewing machines, spinning machines, and fiber-processing machines) that resulted in high levels of MF exposure. A quantitative job–exposure matrix for MF exposure was developed using a combination of work history information collected for all study subjects and direct measures from the contemporary workforce in selected factories in which some of the study participants had worked (W. Li, unpublished data, 2013). Briefly, information on all textile industry jobs that were held by each study subject since the date of her first employment in the STIB was collected by trained field workers through review of factory personnel records (80%), interviews of factory supervisors (12%), and in-person interviews of women or their relatives (8%). For each job that a woman held, the field workers recorded the dates of employment, the workshop, and the performed tasks. A team of occupational exposure–assessment experts in Seattle, including 3 industrial hygienists and 3 occupational epidemiologists, constructed a STIB-specific coding dictionary (12). Using the coding dictionary, 6 STIB industrial hygienists classified textile jobs into 17 categories of major textile manufacturing processes and 13 categories of work types (Appendix Table 1). One or more study subjects had worked in 116 of the major process-work type combinations (hereafter referred to as "positions").

Two STIB factories were initially selected in a random manner to measure MF exposure for each of the 116 positions. However, many factories in the STIB were being closed during the sampling process. When measurements could not be collected from the 2 factories originally selected, the study industrial hygienists identified comparable jobs in the same categories in the remaining open factories. On the days of sample collection, EMDEX II meters (Enertech Consultants, Campbell, California) were positioned at each worker's waist to monitor MF exposure every 10 seconds for 4 to 6 hours during the worker's regular shift.

Direct measurements of MFs were collected in 57 factories from 1,115 workers for 102 of the 116 positions. The number of measurements collected for each position varied from 2 to 46. The time-weighted average level of MF exposure was calculated for each worker. The arithmetic mean in microteslas of the time-weighted averages of all workers in each position was used as the exposure level for the position. The range of arithmetic means for 102 positions was between 0.02 µT and 0.9 µT, with the mean of 0.25 µT. The positions with highest MF exposure were spinning machine operators (0.9 µT) and sewing machine operators (0.81 µT).

The MF job–exposure matrix was linked to all of the jobs held by each study subject during her entire working life in the STIB. We did not have work history information for 54 subjects. One hundred subjects (22 breast cancer cases and 78 noncase subjects) worked in jobs for which we were unable to collect direct measurements or variations of measurements were too large, and thus their data were deleted from further analysis, leaving 1,687 breast cancer cases and 4,702 noncase subjects for the risk estimate analyses. The study was approved by the institutional review boards of the University of Washington, the Fred Hutchinson Cancer Research Center, and the Station for Prevention and Treatment of Cancer of the Shanghai Textile Industry Bureau, in accordance with an assurance filed with the Office for Human Research Protections of the US Department of Health and Human Services.

Statistical analysis

We conducted Cox proportional hazards modeling that was adapted for the stratified case-cohort design to calculate hazard ratios and 95% confidence intervals for breast cancer associated with MF exposure (13). Robust variance estimates were used to compute standard errors of hazard ratios (14). Failure time was defined as time from entry into the cohort until the date of a breast cancer diagnosis; a subject was considered to be at risk until diagnosis, death, or the end of follow-up on July 31, 2000, whichever came first. Because subjects' cumulative exposures changed during follow-up, we organized the analytic dataset into risk sets to accommodate the time-dependent exposures and used the computational methods developed by Langholz and Jiao (15). A risk set was formed for each case of breast cancer, with all other women at risk at the corresponding failure time serving as controls. Thus, both cases selected as the subcohort members and noncases could serve as controls in multiple risk sets. For each risk set, cumulative exposures to MFs were calculated for the cases and controls only up to the failure time. For each position a subject held, cumulative MF exposure was calculated as a product of the assigned exposure value in micro-teslas for the position and the years of employment in that position. If a women held multiple positions during the employment period, the cumulative MF exposure was the sum (μT-years) of the products calculated for each of them. Cumulative exposure during the entire work history was categorized into quartiles, with the cutoff points defined by the distribution of exposure among cases. Dose–response trends were tested by assigning to each quartile group the median exposure value among cases in that group and using a grouped linear model. In addition, the associations of breast cancer with MF exposure were examined by lagging exposure times by 10 or 20 years before the diagnosis of breast cancer to take into account a possible latency period of the effect of exposure to MFs on breast cancer risk.

Levels of MF exposure likely varied in the factories over time because of changes in production machinery or electricity upgrades, with the changes having been relatively uniform across factories within the same sector (e.g., cotton). From our factory visits and review of factory records, we learned that machinery in the factories underwent major changes in the mid-1960s. In particular, electrical sewing machines were installed or replaced the pedal sewing machines, which marked a significant change in MF exposure levels for workers operating those machines. We conducted an additional analysis by computing the cumulative exposure of MFs starting from the year of 1965 for all study subjects, with the assumption that workers who worked before 1965 were exposed to very low levels of MFs at work.

We adjusted for age at the baseline as a linear variable in all analyses. In addition, potential confounders selected a priori included the number of live births (1, 2, 3, 4, or ≥5), age at the first live birth (≤19, 20–24, 25–29, or ≥30 years), lifetime duration of breastfeeding (never or ≤6, 7–12, 13–24, 25–36, 37–48, or ≥49 months), and alcohol consumption (yes vs. no). These variables were included in analytic models testing the association between MF exposure and breast cancer risk one by one. If a variable resulted in a 10% change in the hazard ratio estimate, the factor was included in the final model for estimating the relative risk associated with MF exposures.

Previous research has suggested an association between exposure to MFs and the risk of breast cancer among premenopausal women but not among postmenopausal women. Although we did not have data on age at menopause, we examined a possible effect modification by performing analyses separately for women less than 50 years of age and women 50 years of age or older, which serves a proxy for menopausal status because menopause typically occurs at about the age of 50 years in Chinese women (16). All statistical analyses were performed using SAS, version 9.1 (SAS Institute, Inc., Cary, North Carolina).

Table 1. Characteristics of the Cases and Noncases Among Woman Textile Workers in Shanghai, China, 1989–2000

Characteristic	Cases ($n = 1{,}709$)		Noncases ($n = 4{,}780$)	
	No.	%	No.	%
Birth year				
1925–1929	266	15.56	1,076	22.51
1930–1934	371	21.71	1,146	23.97
1935–1939	173	10.12	514	10.75
1940–1944	113	6.61	249	5.21
1945–1949	252	14.75	448	9.37
1950–1954	335	19.60	624	13.05
1955–1958	199	11.64	723	15.13
Duration of follow up, years[a]	5.19 (2.92)		10.9 (1.35)	
Years of employment in STIB				
≤20	524	30.66	1,354	27.91
21–30	766	44.82	2,183	45.67
31–40	414	24.22	1,236	25.86
>40	5	0.29	27	0.56
No. of jobs held				
1	761	44.53	2,536	53.05
2	635	37.16	1,555	32.53
3	224	13.11	474	9.92
≥4	89	5.21	215	4.50

Abbreviation: STIB, Shanghai Textile Industry Bureau.
[a] Values are presented as mean (standard deviation).

Table 2. Risk of Breast Cancer in Relation to Reproductive History and Lifestyle Factors at Baseline Interview, Shanghai, China, 1989–2000

Risk Factor	Cases (n = 1,709)		Noncases (n = 4,780)		Adjusted for Age		Adjusted for Age and No. of Live Births	
	No.	%	No.	%	HR	95% CI	HR	95% CI
Age at first menstrual period, years								
≤13	179	10.5	450	9.4	1.00	Referent	1.00	Referent
14	315	28.4	794	16.6	1.00	0.81, 1.25	1.02	0.82, 1.27
15	415	29.1	1,013	21.2	1.04	0.85, 1.28	1.05	0.86, 1.30
16	360	25.7	1,041	21.8	0.91	0.74, 1.12	0.93	0.76, 1.16
≥17	439	22.9	1,482	31.0	0.80	0.65, 0.99	0.84	0.68, 1.03
No. of live births								
0	118	6.9	203	4.2	1.32	1.02, 1.70		
1	695	40.7	1,644	34.4	1.00	Referent		
2	367	31.4	802	16.8	1.02	0.85, 1.23		
3	244	23.0	816	17.1	0.67	0.53, 0.84		
4	150	8.8	628	13.1	0.52	0.40, 0.68		
≥5	135	7.9	687	14.4	0.42	0.32, 0.56		
Age at first live birth, years								
Nulliparous	118	6.9	203	4.2	2.42	1.72, 3.42	1.14	0.93, 1.39
≤19	72	4.2	321	6.7	1.00	Referent	1.00	Referent
20–24	462	21.7	1,666	34.8	1.22	0.93, 1.60	1.09	0.82, 1.44
25–29	721	26.9	1,962	41.0	1.52	1.15, 2.00	1.18	0.88, 1.57
≥30	336	34.9	628	13.1	2.14	1.58, 2.88	1.61	1.18, 2.21
Duration of breast feeding, months								
Nulliparous	118	6.9	203	4.2	1.41	1.07, 1.84	1.05	0.84, 1.30
Never breastfed	240	14.0	577	12.1	1.00	Referent	1.00	Referent
≤6	205	28.2	522	10.9	0.93	0.75, 1.16	0.9	0.72, 1.13
7–12	456	29.5	1,090	22.8	0.99	0.82, 1.19	0.96	0.80, 1.16
13–24	298	28.4	750	15.7	0.97	0.79, 1.20	0.91	0.72, 1.15
25–36	185	24.2	580	12.1	0.81	0.64, 1.02	0.94	0.72, 1.23
37–48	102	6.0	426	8.9	0.61	0.46, 0.80	0.77	0.56, 1.05
≥49	105	6.1	632	13.2	0.42	0.32, 0.55	0.56	0.40, 0.77
Cigarette smoking								
No	1,663	97.4	4,607	96.4	1.00	Referent	1.00	Referent
Former user	8	0.5	29	0.6	0.88	0.40, 1.92	0.87	0.39, 1.94
Current user	37	2.2	144	3.0	0.82	0.57, 1.19	0.87	0.60, 1.26
Alcohol use								
No	1,368	80.0	3,845	80.4	1.00	Referent	1.00	Referent
Yes	341	20	935	19.6	0.98	0.85, 1.13	0.99	0.86, 1.14

Abbreviations: CI, confidence interval; HR, hazard ratio.

RESULTS

All women entered the follow-up period between the ages of 30 and 66 years. As shown in Table 1, breast cancer cases tended to be slightly younger than women in the comparison group. The average durations of follow-up for cases and noncases were 5.2 and 10.9 years, respectively. Most of the women had worked in the STIB for more than 20 years.

As shown in Table 2 and reported previously (7), the risk of breast cancer was lower in women with a late age at menarche and decreased with number of live births. Risk was elevated in nulliparous women and increased with increasing age at first live birth. Risk was decreased in women with more than 4 years of breast feeding. There were few cigarette smokers, and approximately 20% of the subjects had ever consumed alcohol. Neither of these factors was associated with risk of breast cancer.

Risk of breast cancer in relation to cumulative MF exposure for the entire employment period and for exposures lagged by 10 and 20 years are shown in Table 3. Hazard ratio estimates

Table 3. Risk of Breast Cancer in Relation to Cumulative Magnetic Field Exposure Among Textile Workers in the Shanghai Textile Industry, Shanghai, China, 1989–2000[a]

Cumulative Exposure, μT-years	No. of Cases	HR[b]	95% CI
Entire employment period			
>0–2.70	422	1.00	Referent
>2.70–4.13	422	1.13	0.97, 1.33
>4.13–6.24	422	1.01	0.86, 1.18
>6.24	421	1.03	0.87, 1.21
P for trend[c]			0.858
10-year lag			
>0–2.70	673	1.00	Referent
>2.70–4.13	358	1.00	0.86, 1.17
>4.13–6.24	278	0.83	0.70, 0.98
>6.24	346	1.00	0.85, 1.18
P for trend			0.902
20-year lag			
>0–2.70	821	1.00	Referent
>2.70–4.13	211	0.75	0.63, 0.89
>4.13–6.24	180	0.93	0.76, 1.12
>6.24	200	0.89	0.74, 1.08
P for trend			0.277
Since the year of 1965			
>0–2.70	696	1.00	Referent
>2.70–4.13	457	1.12	0.98, 1.29
>4.13–6.24	269	1.06	0.89, 1.26
>6.24	255	0.93	0.78, 1.10
P for trend			0.844

Abbreviations: CI, confidence interval; HR, hazard ratio.
[a] Based on 1,687 cases and 4,702 noncases.
[b] Adjusted for age at the beginning of follow-up as a continuous variable.
[c] Trend tests used the median values of each quartile as the score variable.

for the 3 highest quartiles of exposure were mostly close to unity compared with estimates for the first quartile. No trends in risk with level of exposure were observed, and the results were similar when only exposure after 1965 was considered. The results were not materially changed when analyses were repeated including adjustments for number of live births, age at first live birth, and alcohol consumption (data not shown).

As shown in Table 4, risks of breast cancer in women less than 50 years of age were elevated for the second and third quartiles but not the highest quartile of total cumulative MF exposure. No increasing trend in risk with total MF exposure was observed. Similar results were observed for cumulative exposure since 1965. Statistically significant decreasing trends in risk with level of exposure were observed for exposures lagged by 10 and 20 years. For women 50 years of age or older, no association between breast cancer risk and cumulative MF exposure was observed for the entire work history or for the 3 exposure windows considered.

We estimated the hazard ratios for breast cancer by duration of high exposure by comparing 1,161 cases and 3,315 noncases who either had high (>0.3 μT) or low (≤0.16 μT) levels of exposure to MFs. Women with the low level of exposure served as the reference group. No association was found between duration of exposure to high levels of MFs and risk of breast cancer in either age group of women (Table 5).

DISCUSSION

Findings from this case-cohort study of textile workers who experienced a wide range of occupational exposure to MFs do not support the hypothesis that MF exposure increases the risk of breast cancer. Although a moderately elevated risk of breast cancer was observed in some categories of exposure for premenopausal women, no consistent associations or increasing trends in risk with level of exposure were found.

Associations between the risk of breast cancer and MF exposure have been investigated in residential and occupational studies. Two primary sources evaluated in residential exposure were electric blankets and power lines surrounding residences. In 2007, the World Health Organization Environmental Health Criteria Programme reviewed the data concerning the risk of breast cancer associated with MF exposure and concluded that the evidence do not support an association between MF exposure and the risk of breast cancer (4). The evidence reviewed by World Health Organization Environmental Health Criteria Programme was mostly from investigations of residential MF exposures and breast cancer. Studies on occupational exposures to MF were very limited. Most of the prior studies were population-based case-control studies, and their results indicated little or no overall association (17–21); however, some suggested moderately elevated risks (22) or associations restricted to premenopausal women (19, 23).

Only one cohort study has reported on occupational MF exposure in relation to female breast cancer risk. In that follow-up study of Norwegian female radio and telegraph operators, cumulative exposure was estimated based on ship type and number of years of employment (24). Increased risk of breast cancer was found in the exposed occupations as compared with the general population (standardized incidence ratio = 1.3, 95% confidence interval: 1.1, 1.6), but results were unstable because there were a small number of exposed cases and possible confounding by exposure to light at night.

Our study has several notable strengths. The study was conducted in a large, well-defined cohort of textile workers. A quantitative job–exposure matrix was developed based on more than 1,000 direct measurements collected in the STIB factories. Occupations were identified with MF exposures as high as 0.90 μT (spinning machine operators) and 0.81 μT (sewing machine operators) and as low as 0.02 μT (technicians) and 0.06 μT (administrators). The average level of exposure for all 102 positions studied was 0.25 μT, which is considerably higher than the average level of exposure to MF (<0.1 μT) in the general population in Western countries (4). The large size of the breast cancer case group, the broad range of MF exposures experienced by the subjects, and availability of complete work history information provided sufficient statistical power to test the hypothesis that MFs are associated with a modest increase in the risk of breast cancer. In addition, data

Table 4. Risk of Breast Cancer in Relation to Cumulative Magnetic Field Exposure at Work for Cases Stratified by Age at Diagnosis, Shanghai, China, 1989–2000

Cumulative Exposure, μT-years	No. of Cases	HR[a]	95% CI
	Diagnosed at <50 Years of Age (n = 727)		
Entire employment period			
>0–2.37	181	1.00	Referent
>2.37–3.48	182	1.34	1.06, 1.69
>3.48–4.83	181	1.32	1.03, 1.69
>4.83	183	0.96	0.75, 1.22
P for trend[b]			0.193
10-year lag			
>0–2.37	419	1.00	Referent
>2.37–3.48	134	0.94	0.75, 1.17
>3.48–4.83	56	0.85	0.62, 1.16
>4.83	88	0.79	0.60, 1.04
P for trend			0.041
20-year lag			
>0–2.37	419	1.00	Referent
>2.37–3.48	19	0.61	0.38, 1.00
>3.48–4.83	14	0.99	0.56, 1.75
>4.83	17	0.56	0.33, 0.96
P for trend			0.024
Since the year of 1965			
>0–2.37	181	1.00	Referent
>2.37–3.48	183	1.34	1.06, 1.69
>3.48–4.83	181	1.32	1.03, 1.69
>4.83	182	0.96	0.75, 1.22
P for trend			0.193
	Diagnosed at ≥50 Years of Age (n = 960)		
Entire employment period			
>0–3.22	240	1.00	Referent
>3.22–4.75	240	0.98	0.78, 1.22
>4.75–7.12	240	1.11	0.89, 1.39
>7.12	240	1.06	0.85, 1.32
P for trend[b]			0.496
10-year lag			
>0–3.22	286	1.00	Referent
>3.22–4.75	243	0.89	0.71, 1.10
>4.75–7.12	210	1.07	0.86, 1.33
>7.12	219	1.00	0.81, 1.25
P for trend			0.553
20-year lag			
>0–3.22	461	1.00	Referent
>3.22–4.75	191	0.91	0.74, 1.10
>4.75–7.12	141	1.31	1.04, 1.65
>7.12	151	0.97	0.77, 1.22
P for trend			0.892
Since the year of 1965			
>0–3.22	513	1.00	Referent
>3.22–4.75	205	1.01	0.81, 1.25
>4.75–7.12	115	1.36	1.01, 1.82
>7.12	118	0.92	0.70, 1.19
P for trend			0.693

Abbreviations: CI, confidence interval; HR, hazard ratio.

[a] Adjusted for age at the beginning of follow-up as a continuous variable.

[b] Trend tests used the median values of each quartile as the score variable.

were available for some of the most important established nonoccupational risk factors for breast cancers, which allowed us to control for potential confounding.

Of primary concern in our study is exposure misclassification. Although our job–exposure matrix was based on direct measurements of personal exposures, numerous textile industry jobs were grouped into broad job categories based on similarity of work activity and environment, which could have led to exposure misclassification. Categories that included relatively homogenous job activities, such as operators of weaving machines and of sewing machines, are less likely to suffer exposure misclassification than the categories including a wide variety of jobs, such as quality control in finishing and packing or machine maintenance. We expect that exposure misclassification was minimal, as the most frequently held jobs were relatively homogenous job activities. Findings from ancillary analyses of associations with duration of relatively low (≤0.16 μT) and high (>0.3 μT) exposure levels (Table 5) corroborated the main exposure–response patterns.

Personal measurements were convenience samples collected from the contemporary workforce of 57 study factories. While evaluating the job–exposure matrix, we found that work environment and machinery configuration can contribute to exposure variation from factory to factory, even within the same jobs. Developing a job–exposure matrix based on measurements in all 503 factories was not feasible because almost 400 were closed when we obtained the measurements, and historical exposure information of MF in the STIB factories was not available. If older machines produced stronger MFs than newer machines, long-term MF exposure experienced by subjects would be underestimated by using a job–exposure matrix developed based on contemporary measurements. Nevertheless, it is reassuring that exposure intensity for some highly exposed textile jobs, such sewing machine operators, in our job–exposure matrix are comparable to the exposure level of the same occupations reported by others (25). On balance, exposure misclassification was probably nondifferential and may have biased findings toward the null. Nonetheless, it seems unlikely that such bias masked strong associations.

Table 5. Risk of Breast Cancer in Relation to Duration of Years Worked on Jobs With High Magnetic Field Exposures, Shanghai, China, 1989–2000[a]

Magnetic Field Exposure >0.3 μT	No. of Cases	All Women		Reference Age <50 Years		Reference Age ≥50 Years	
		HR[b]	95% CI	HR[b]	95% CI	HR[b]	95% CI
Entire employment period							
No[c]	738	1.00	Referent	1.00	Referent	1.00	Referent
Yes, >0–5 years	25	0.92	0.58, 1.45	0.79	0.38, 1.63	1.04	0.58, 1.86
Yes, >5–10 years	152	1.23	0.83, 1.83	1.30	0.77, 2.18	1.12	0.62, 2.03
Yes, >10–20 years	114	0.93	0.60, 1.45	0.98	0.71, 1.37	1.39	0.99, 1.94
Yes, >20 years	132	0.77	0.62, 0.95	0.50	0.33, 0.76	0.91	0.72, 1.16
10-year lag							
No[c,d]	709	1.00	Referent	1.00	Referent	1.00	Referent
Yes, >0–5 years	37	0.86	0.59, 1.25	0.81	0.50, 1.32	0.93	0.52, 1.68
Yes, >5–10 years	164	1.06	0.78, 1.46	1.01	0.69, 1.47	1.17	0.66, 2.07
Yes, >10–20 years	107	0.92	0.64, 1.33	0.72	0.45, 1.15	1.12	0.59, 2.11
Yes, >20 years	99	0.84	0.67, 1.07	0.21	0.05, 0.88	0.92	0.72, 1.18
20-year lag							
No[c,d]	592	1.00	Referent	1.00	Referent	1.00	Referent
Yes, >0–5 years	64	0.92	0.68, 1.25	0.83	0.58, 1.20	1.03	0.62, 1.72
Yes, >5–10 years	136	0.88	0.64, 1.22	0.60	0.39, 0.92	1.10	0.71, 1.71
Yes, >10–20 years	83	1.21	0.83, 1.76			1.13	0.69, 1.83
Yes, >20 years	56	0.81	0.59, 1.10			0.76	0.45, 1.28

Abbreviations: CI, confidence interval; HR, hazard ratio.
[a] Based on 1,161 cases and 3,315 noncases.
[b] Adjusted for age at the beginning of follow-up as a continuous variable.
[c] The comparison group included only the women who worked on jobs with low magnetic field exposure (<0.16 μT).
[d] Forty-five and 230 cases worked fewer than 10 and 20 years, respectively, and were not included in the analysis.

The component of MF that might be biologically relevant to the development of breast cancer is uncertain (26, 27). Time-weighted average has been investigated most frequently and is the parameter evaluated in the present study. We know of no evidence indicating that other indices of MF would be more important in the etiology of breast cancer (27).

Our study is, to our knowledge, the largest investigation of MF exposure and breast cancer ever conducted in the textile industry, which is known to include jobs with relatively high exposures to MF. A quantitative job–exposure matrix based on direct measurements was developed. This study does not support the hypothesis that MF exposure increases the risk of breast cancer.

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Appendix Table 1. Textile Jobs Grouped Into 17 Major Manufacturing Processes and 13 Work Types, Shanghai, China, 1989–2000

Major Process Groupings	Work Type Groupings
Warehouse	Operator of production equipment
Material handling	Nonmechnical laborer
Fiber processing	Special-skilled personnel (e.g., technician)
Spinning	Floor supervisor
Scouring/bleaching	Tester
Dyeing	Administrative staff
Textile finishing	Machine maintenance mechanics
Weaving/knitting/fabric manufacturing	Factory maintenance staff
Printing	Custodial staff
Cutting/sewing	Medical personnel
Finishing/packaging	Education personnel
Testing/quality control	Support services
Maintenance	Electricians/Welders
Administration/general affairs	
Nonproduction (e.g., supply, sales, and cafeteria)	
Machine manufacturing/ metal-working	
Manufacturing of nonmetal parts (e.g., paper roll or rubber manufacturing)	