Follow-up of radio and telegraph operators with exposure to electromagnetic fields and risk of breast cancer

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It is still unclear whether exposure to electromagnetic fields (EMF) is associated with breast cancer. To further investigate the issue, we followed-up a cohort of Norwegian female radio and telegraph operators in the period 1 January 1961 to 31 May 2002, with 99 breast cancer cases. The standardized incidence ratio (SIR) for breast cancer was 1.30 (95% confidence intervals (CI) 1.05–1.58), compared with the total Norwegian female population. In a subsequent nested case–control study, exposure to radio frequency (405 kHz–25 MHz) and extremely low-frequency (50 Hz) fields due to stay in the radio room during day and night was cumulated by years of employment and workload according to ship type. The exposure was assessed in two age groups (<50, 50+) with regard to risk of breast cancer. The odds ratios in the group with the highest cumulative exposure were 1.78 (95% CI 0.59–5.41) and 2.37 (95% CI 0.88–6.36) in the younger and the older women, respectively. *P*-value for trend was 0.03 in both age groups. The results of the oestrogen receptor status analysis by exposure to EMF showed an increased risk of oestrogen receptor-positive breast cancer in the younger women, while the older age group had an elevated risk of oestrogen receptor-negative breast cancer. Thus, the present study contributes to the hypothesis of an association between occupational exposure to EMF and increased risk of breast cancer. *European Journal of Cancer Prevention* 12:301–307 © 2003 Lippincott Williams & Wilkins.

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Introduction

Breast cancer risk in women is substantially higher in industrialized countries compared with less industrialized countries (Parkin *et al.*, 2001), and there are so far few established aetiological factors except fertility (Kvåle *et al.*, 1987). Epidemiological studies have suggested a link between occupational and environmental exposure to electromagnetic fields (EMF) and cancer, and the International Agency for Research on Cancer evaluated the link in 2002 and concluded that extremely low-frequency magnetic fields are possibly carcinogenic to humans, based on the association of higher level residential magnetic fields and increased risk for childhood leukaemia. For breast cancer in humans, the evidence was considered to be inadequate (IARC, 2002).

Both positive and negative results have been reported from studies in men and women with occupational exposure to EMF and breast cancer. The first reports of an excess risk of breast cancer came from studies among male electrical workers exposed to EMF (Tynes and Andersen, 1990; Demers *et al.*, 1991; Matanoski *et al.*, 1991), but a later study among male electric utility workers did not confirm such a finding (Theriault *et al.*, 1994). These authors found only seven cases of male breast cancer in their cohort but numbers were too small for formal analysis, nor was this subtype considered *a priori*. In women, the first report of an association between occupational exposure to EMF and breast cancer was published in 1994 (Loomis *et al.*, 1994), and was later supported by two other studies (Coogan *et al.*, 1996; Kliukiene *et al.*, 1999). Two recent studies in women showed a stronger association for premenopausal women (Forssen *et al.*, 2000; Van Wijngaarden *et al.*, 2001). However, four Scandinavian studies reported no elevated risk of breast cancer among women in occupations related to electrical devices (Våger and Olin, 1983; Våger *et al.*, 1985; Guenel *et al.*, 1993; Johansen and Olsen, 1998).

Residential studies have also yielded mixed results. One study showed an association between breast cancer mortality and exposure to EMF (Wertheimer and Leeper, 1987), another study indicated an elevated risk in exposed women under the age of 50 (Feychting *et al.*, 1998a), but some other studies did not support such an association (McDowall, 1986; Schreiber *et al.*, 1993; Verkasalo *et al.*, 1996; Li *et al.*, 1997).

Four of the studies in women also provided data on oestrogen receptor (ER) status (Feychting *et al.*, 1998a; Gammon *et al.*, 1998; Forssen *et al.*, 2000; Van Wijngaarden *et al.*, 2001), and three of the studies were consistent about increased risk for ER-positive breast cancer (Feychting *et al.*, 1998a; Van Wijngaarden *et al.*, 2001; Forssen *et al.*, 2000).

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Stevens (1987) proposed a biological mechanism whereby EMF and light at night might contribute to a hormone-related type of cancer. The hypothesis was supported by experimental studies on animals indicating that the pineal hormone melatonin inhibits the growth of breast cancer (Tamarkin *et al.*, 1981; Narito and Kudo, 1985). Other studies showed that chronic exposure to electric fields can abolish the normal nocturnal peak in pineal melatonin in rats (Wilson *et al.*, 1981, 1983). An oncostatic effect of melatonin on ER-positive breast cancer cells in human has also been demonstrated (Hill and Blask, 1988), and magnetic field exposure has been shown to block this effect (Liburdy *et al.*, 1993).

The Norwegian cohort of radio and telegraph operators has been followed for breast cancer before, but that study was based on few breast cancer cases, and no final conclusion could be drawn (Tynes *et al.*, 1996). The present study includes an extended follow-up with more breast cancer cases, more detailed exposure data, and data on ER status.

Materials and methods

Cohort information

A cohort of all 2619 women who were certified as radio and telegraph operators between 1920 and 1980 by Norwegian Telecom was established, and a more detailed description is given elsewhere (Tynes *et al.*, 1996). In the present study, the cohort was followed for breast cancer from January 1961 to the end of May 2002. All breast cancer cases were identified by linkage to the Cancer Registry of Norway, by the unique personal identification number, and 49 cases were identified in addition to the 50 cases from the first follow-up of the cohort. All new cases of cancer in Norway have been recorded by the Cancer Registry since 1953 (Pedersen and Magnus, 1959). For an individual, two primary breast cancers may be registered (Cancer Registry of Norway, 1995). All causes of death on death certificates are coded by Statistics Norway and reported regularly to the Cancer Registry. Date of emigration and fertility data were available from Statistics Norway. Information on ER status was obtained for 68 of the cases from pathological laboratories or clinical chemistry departments.

Nested case–control study

We also did a nested case–control study within the present cohort. All 99 breast cancer cases from the follow-up period were included. Four controls for each case were selected from the cohort, 396 controls alive at time of diagnosis and matched on year of birth (for women born before 1920 ± 5 years, for those born 1920 or later ± 1 year). Reference category in the case–control study was women certified as radio and telegraph operators with no job history at merchant ships registered in the Norwegian Seamen Registry. This reference group (14 cases and 83 controls) was also checked with regard to occupation against data from censuses of 1960, 1970 and 1980 to be sure of no career at sea. Those with occupation as radio and telegraph operators at sea at least at one of the censuses (eight controls) were considered as being exposed with unknown cumulative exposure, and excluded from the reference group and from the analysis. The distribution of demographic data and exposure among cases and controls after exclusion is presented in Table 1. As a result of the matched design, age distribution was similar, however, cases showed a somewhat higher proportion of women without children. A higher proportion of cases was also shown in the highest exposure group.

Exposure assessment

Results of EMF spot measurements in the radio rooms of some Norwegian ships are described elsewhere (Tynes *et al.*, 1996). Potential occupational exposure to light at

Table 1 **Distribution of breast cancer cases and controls in radio and telegraph operators**

	Cases ($n=99$)		Controls ($n=388$)	
	n	%	*n*	%
Cumulative exposure to EMF due to stay in radio room (category × years)				
none	14	14.1	75	19.3
>0– ≤ 2.57	24	24.2	104	26.8
>2.57– ≤ 5.19	21	21.2	104	26.8
>5.19	40	40.4	105	27.1
Marital status				
ever married	86	86.9	351	90.5
never married	13	13.1	36	9.3
unknown	0	0	1	0.3
Mean age at first birth	27.8		27.4	
Mean number of children	2.1		2.1	
Number of women without children	25	25.3	80	20.6
Age <50 years	44	44.4	180	46.4
Age 50+ years	55	55.6	208	53.6

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night, radio frequency (405 kHz–25 MHz) and exposure to extremely low-frequency (50 Hz) electromagnetic fields was calculated based on duration of employment as a radio and telegraph operator at sea and on category of the ships with regard to frequency of exposure. Detailed job histories on merchant ships were collected from the Norwegian Seamen Registry. Each ship in the job histories was classified into exposure category by a shipping researcher experienced about the history of Norwegian merchant ships. The classification aimed to define workload and consequently the stay in the radio room both at night and during the day, with a possible exposure to EMF. A ship was assigned a rank of 1, or category 'long voyage', if it was either a tanker or dry-cargo ship with longer stays at sea between ports of discharge. A rank of 2, or category 'many calls', was assigned to the overseas liner trade ships, e.g. trans-atlantic or between the western coast of the USA and Europe, that had several loading and discharge ports, to the ships with up to 12 passengers, and to ships involved in local shipping. A rank of 3 was assigned to a passenger ship where radio and telegraph operators had the highest workload.

Exposure was cumulated as a category multiplied by employment years. Categories of cumulative exposure were designed by dividing all exposed controls into three equal groups, i.e. by 33 percentiles.

Analysis

For the SIR analysis, person-years at risk were calculated from the date of certification or 1 January 1961, whichever came last, to the date of death or emigration, or to the end of May 2002, whichever came first. The basic unit of statistical computation was the number of follow-up years for each member of the cohort, summed by age and calendar year. The expected number of cancer cases was calculated using the 5-year, age-specific incidence rates for the total Norwegian female population for each year from 1961 to 2002. The SIR was calculated for the total cohort and for the two age groups; namely < 50 years, and 50 or beyond. The computation was performed using a standard computer program Epicure (Preston *et al.*, 1993). Ninety-five per cent confidence intervals (CI) were determined assuming a Poisson distribution of the observed number of breast cancer and using a two-sided test of significance. The result was regarded as statistically significant if the confidence interval (CI) did not include 1.0.

For the case–control analysis, the odds ratio (OR) was used as the measure of association between exposure and disease and was computed by conditional logistic regression models for matched sets with the software package EGRET (SERC Inc., 1988). In the models evaluating cumulative exposure either as a continuous variable or as a categorical variable, the following potential confounders were included: age at first birth and number of children. Potential induction and latency periods were investigated by lagging exposure 0, 10 and 20 years (Checkoway *et al.*, 1990). For example, a lag of 20 years means that exposure during the last 20 years prior to the observation was disregarded. The *P*-value from the adjusted model evaluating cumulative exposure as a continuous variable is given as *P*-value for trend. Risk of breast cancer was evaluated in two age groups: younger than 50 and 50 years or older. In addition, data were analysed according to ER status. In the analysis of risk for ER-negative breast cancer among women aged 50 or older, no case was observed among non-exposed women. Therefore the reference group included both non-exposed women and women in the lowest exposure group.

Results

Cohort analysis for SIR

During the follow-up period 1 January 1961 to 31 May 2002 (81 044 person-years), 99 new cases of breast cancer were observed, and the SIR was 1.30 (95% CI 1.05–1.58) (Table 2). Similar SIR was for both those aged < 50 and for those aged 50 or older.

Nested case–control analysis

The OR for all exposed radio and telegraph operators compared with non-exposed was 1.43 (95% CI 0.74–2.74), and the ORs were the same in both age groups of < 50 and $50+$ (Table 3). In the analysis by exposure categories, a statistically significant trend was observed for cumulative exposure both in women younger than 50 and 50 or older. In the highest exposure category the ORs were 2.02 (95% CI 0.97–4.22) for all ages combined, 1.78 (95% CI 0.59–5.41) for women younger than 50, and 2.37 (95% CI 0.88–6.36) for women of age 50 or older. For all ages combined, the trend for the exposure remained

Table 2 Observed (Obs) numbers of new breast cancer cases and standardized incidence ratios (SIR) by age groups, 2619 Norwegian female radio and telegraph operators, follow-up 1 January 1961 to 31 May 2002

Age (years)	Person-years	Obs	SIR	95% CI
All	81 044	99	1.30	1.05–1.58
<50	60 380	44	1.35	0.98–1.81
$50+$	20 664	55	1.26	0.95–1.64

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Table 3 Odds ratios (OR) for breast cancer in Norwegian female radio and telegraph operators by cumulative exposure to electromagnetic fields in radio rooms

	All					<50 years					50+ years				
	Cases ($n=99$)	Controls ($n=388$)	OR[a]	95% CI	*P*-value for trend	Cases ($n=44$)	Controls ($n=180$)	OR[a]	95% CI	*P*-value for trend	Cases ($n=55$)	Controls ($n=208$)	OR[a]	95% CI	*P*-value for trend
Cumulative exposure to EMF (category × years)															
No lag															
none	14	75	1			6	34	1			8	41	1		
All exposed	85	313	1.43	0.74–2.74		38	146	1.41	0.54–3.69		47	167	1.41	0.58–3.42	
>0– ≤ 2.57	24	104	1.27	0.60–2.67		13	58	1.28	0.45–3.70		11	46	1.33	0.45–3.95	
> 2.57– ≤ 5.19	21	104	1.15	0.54–2.47		11	45	1.28	0.41–4.02		10	59	0.87	0.30–2.49	
>5.19	40	105	2.02	0.97–4.22		14	43	1.78	0.59–5.41		26	62	2.37	0.88–6.36	
Trend					0.0045					0.0345					0.0319
Lag 10 years															
none	17	81	1			7	39	1			10	42	1		
>0– ≤ 2.57	24	112	1.01	0.50–2.07		14	65	1.21	0.45–3.26		10	47	0.96	0.32–2.87	
> 2.57– ≤ 5.19	22	102	1.06	0.51–2.21		12	43	1.38	0.46–4.15		10	59	0.72	0.26–2.03	
>5.19	36	93	1.79	0.89–3.60		11	33	1.78	0.62–5.13		25	60	1.87	0.71–4.88	
Trend					0.0354					0.0910					0.0994
Lag 20 years															
none	40	145	1			26	100	1			14	45	1		
>0– ≤ 2.57	18	106	0.63	0.33–1.21		9	56	0.70	0.29–1.72		9	50	0.67	0.25–1.81	
>2.57– ≤ 5.19	17	80	0.84	0.40–1.73		6	16	1.51	0.44–5.16		11	64	0.56	0.22–1.43	
>5.19	24	57	1.63	0.79–3.38		3	8	2.95	0.50–17.30		21	49	1.50	0.61–3.72	
Trend					0.0977					0.1284					0.1633

[a]Adjusted for age at first birth and number of children.

significant also when 10 years of exposure before diagnosis was disregarded, while when 20 years of exposure prior to diagnosis were disregarded, the trend was not significant. In the latter analyses, the reference groups included exposed persons with lag < 10 years or lag < 20 years, respectively. However, when these exposed persons were disregarded and the same reference group of 14 unexposed cases and 75 unexposed controls was used in calculations with lag times, the results became stronger. In the analysis with lag of 20 years, the OR increased from 1.04 to 3.34 in the groups of low and high exposure, respectively, and a significant trend by cumulative exposure was observed ($P = 0.0223$) (not in table).

When the material was stratified by ER status, for all ages combined the OR in exposed women compared with non-exposed was 1.02 (95% CI 0.41–2.55) for ER-positive breast cancer and 2.76 (95% CI 0.54–14.02) for ER-negative cancer (Table 4). The corresponding ORs in women younger than 50 were 1.14 (95% CI 0.28–7.32) and 1.05 (95% CI 0.16–7.11). In women aged 50 or older the OR for ER-positive breast cancer was 0.85 (95% CI 0.27–2.66), while the OR for ER-negative breast cancer was not calculated because no cases were observed in the non-exposed group.

Table 4 also presents the results by receptor status and exposure category. For all ages combined, the increased risk in the highest exposure category was observed both for ER-positive and ER-negative breast cancer with highest risk for ER-negative cancer. However, this result is based on a small number of cases. In women younger than 50, increased risk by cumulative exposure was observed for ER-positive breast cancer, but not for ER-negative breast cancer. In women aged 50 or older, no increased risk was observed for ER-positive breast cancer, while the results in the latter age group indicated an increased risk for ER-negative breast cancer. This result was also based on small numbers.

Discussion

The present study showed an elevated risk by cumulative exposure to EMF both in women younger than 50 years and in those aged 50 or older. The results indicate a dose–response showing highest risk among those with highest exposure in both age groups. No additional information was obtained from the lag analysis when the reference groups included exposed persons with lag < 10 years or lag < 20 years, respectively. However, when the reference group did not include the exposed women, a significant trend by cumulative exposure was observed with a lag of 20 years. The results of the present analysis

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Table 4 Odds ratio (OR) for breast cancer in Norwegian female radio and telegraph operators by oestrogen receptor (ER) status and cumulative exposure to electromagnetic fields in radio rooms

	ER+					ER−				
	Cases	Controls	OR[a]	95% CI	*P*-value for trend	Cases	Controls	OR[a]	95% CI	*P*-value for trend
All ages	*n*=48	*n*=188				*n*=20	*n*=77			
Cumulative exposure to EMF (category × years)										
none	8	34	1			2	16	1		
All exposed	40	154	1.02	0.41–2.55		18	61	2.76	0.54–14.02	
>0– ≤ 2.57	7	38	0.76	0.23–2.51		6	23	2.23	0.38–13.21	
>2.57– ≤ 5.19	12	54	0.96	0.34–2.76		5	21	2.42	0.40–14.67	
>5.19	21	62	1.29	0.46–3.59		7	17	4.11	0.69–24.34	
Trend					0.0629					0.4557
<50 years	*n*=18	*n*=75				*n*=9	*n*=37			
Cumulative exposure to EMF (category × years)										
none	2	12	1			2	6	1		
All exposed	16	63	1.14	0.28–7.32		7	31	1.05	0.16–7.11	
>0– ≤ 2.57	4	22	1.04	0.15–7.21		3	13	1.05	0.13–8.42	
>2.57– ≤ 5.19	5	20	1.46	0.24–8.84		3	9	1.35	0.12–15.39	
>5.19	7	21	1.89	0.31–11.48		1	9	0.79	0.05–13.29	
Trend					0.8502					0.6533
50+ years	*n*=30	*n*=113				*n*=11	*n*=40			
Cumulative exposure to EMF (category × years)										
none	6	22	1			0	10	–		
All exposed	24	91	0.85	0.27–2.66		11	30	–[b]		
>0– ≤ 2.57	3	16	0.80	0.16–3.91		3	10	1[c]		
>2.57– ≤ 5.19	7	34	0.69	0.18–2.65		2	12	1.33	0.13–13.06	
>5.19	14	41	1.04	0.29–3.80		6	8	7.47	1.11–50.23	
Trend					0.4729					0.1359

[a]Adjusted for age at first birth and number of children.
[b]The OR was not calculated; no cases were observed in the non-exposed group.
[c]The reference group includes non-exposed subjects and subjects in the lowest exposure category, i.e. 3 cases and 20 controls.

by cumulative exposure and oestrogen receptor status indicate an increased risk for ER-positive breast cancer and no excess risk for ER-negative breast cancer in radio and telegraph operators younger than 50 years, but in the group of 50 or older an opposite tendency was shown; no excess risk was found for ER-positive breast cancer, while an elevated risk was indicated for ER-negative breast cancer.

Our findings of an increased risk of breast cancer in radio and telegraph operators younger than 50 years are in line with the results of the two recent studies (Forssen *et al.*, 2000; Van Wijngaarden *et al.*, 2001). The findings of the present study are also in accordance with the previous investigation of the same cohort in 1996 (Tynes *et al.*, 1996), where an increased risk for radio and telegraph operators aged 50 years and over was found.

The present results support the importance of oestrogen receptor status in the development of breast cancer. A link between EMF, melatonin and ER-positive breast cancer was indicated by Liburdy *et al.* (1993). The present excess risk for ER-positive breast cancer in women younger than 50 years is in accordance with the results from other positive studies of occupational exposure to EMF (Forssen *et al.*, 2000; Van Wijngaarden *et al.*, 2001). However, the indication for elevated risk of ER-negative breast cancer in women aged 50 years and over is based on small numbers and therefore needs further investigation.

The dose–response shown in our study is in agreement with some of the previous reports that have indicated a dose–response relationship (Vena *et al.*, 1991, 1994; Coogan *et al.*, 1996; Tynes *et al.*, 1996; Feychting *et al.*, 1998a; Kliukiene *et al.*, 1999; Forssen *et al.*, 2000).

The strength of the present study is population-based complete data, with information from the Norwegian Telecom about all women educated as radio and telegraph operators between 1920 and 1980, from the Norwegian Seamen Registry, Statistics Norway and the Cancer Registry of Norway. The present study includes almost 80 000 person-years with complete follow-up of breast cancer and date of death or emigration. This is due to the unique person identification number that has been used for the linkages. In our analysis, we also adjusted for fertility factors (age at first birth and number of children) that are well-known risk factors for breast cancer (Kvåle *et al.*, 1987).

We used the duration of employment at sea and type of ship for the classification of exposure levels. The definition of exposure in the present study includes limitations and could certainly lead to exposure misclassification. Our allocation to the exposure groups most

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likely led to a dilution of real exposure, therefore might have contributed to the observed reduction of the actual risk. The possible misclassification of exposure, however, might also be a methodological problem which inhibits valid conclusions about an association between EMF and breast cancer (Erren, 2001).

Radio and telegraph operators might have had more irregular work hours, and sleep deficit was a common problem, in particular on ships which contacted many ports. This factor could not have been sorted out from our data but may be correlated with the classification of stay in radio room. Travelling through time zones might have also had an impact on the sleep deficit, but this information was not available. The question might also be raised which component of the exposure (electric or magnetic) was the active parameter; the electric component of the electromagnetic wave becomes dominant, as a larger higher frequency component of the exposure is expected in a radio room.

Another limitation might be that our study was restricted to potential occupational exposure, and no data on residential exposure were available. A study evaluating combined residential and occupational EMF exposures reported no increased relative risk (RR) for women of all ages, but when analysis was restricted to women younger than 50 years, an increased RR was observed (the small number of only four cases yielded very wide confidence limits) (Forssen *et al.*, 2000).

The population of seamen, which was our study population, might be exposed more heavily to such factors as a diet rich in fat and an excessive use of alcohol. The analysis of cancer risk among women in other jobs at sea in the occupational-cancer cohort, however, did not indicate that the results were confounded by these factors (Tynes *et al.*, 1996).

A biological mechanism explaining how EMF and light at night might contribute to breast cancer has been investigated over the two last decades. Cohen and co-workers (1978) suggested that the lowered production of melatonin by the pineal gland might increase circulating levels of oestrogen, stimulate the proliferation of breast tissue and could subsequently lead to the development of breast cancer. Later, a hypothesis whereby EMF and light at night might contribute to breast cancer was proposed by Stevens (1987). One of the possible mechanisms might be that EMF lowers melatonin levels, leading to increased oestrogen levels and to the stimulation of turnover of the breast epithelial cells at risk (Stevens, 1987). Another possible explanation is that the EMF lowers melatonin levels, which in turn release existing cancer cells from a quiescent state (Stevens, 1993). A few experimental studies on animals in the early 1980s indicated that the pineal hormone melatonin inhibits the growth of breast cancer *in vivo* and *in vitro* (Tamarkin *et al.*, 1981; Narito and Kudo, 1985).

A meta-analysis of epidemiological studies of electric and magnetic fields and breast cancer reviewed 43 publications that provide information about the possible association between exposure to EMF at work or at home and risk of breast cancer in women and men (Erren, 2001). Estimation of relative risk associated with exposure was evaluated in 24 and 15 studies among women and men respectively. The pooled RR from the studies in women was 1.12 (95% CI 1.09–1.15). This result was unlikely to be due to chance ($P = 0.0365$). Given cancer latencies of 20–30 years and ubiquitous sources of EMF, it may be important to assess total exposures both at home and at work, and over decades of time (Erren, 2001).

Light at night is another product of electric power generation that might also contribute to the development of breast cancer according to the 'melatonin hypothesis'. Melatonin serum levels in humans decrease when people are exposed to light at night (Lewy *et al.*, 1980). Furthermore, low serum melatonin concentrations have been found in women with ER-positive breast cancer (Brzezinski, 1997). Work at night is a common occupational exposure, and three recent studies of this exposure support a hypothesis that light at night may be a potential risk factor of breast cancer (Davis *et al.*, 2001; Hansen, 2001; Schernhammer *et al.*, 2001).

Another support for the melatonin hypothesis also comes from studies on blind women (Hahn, 1991; Coleman and Reiter, 1992; Feychting *et al.*, 1998b; Verkasalo *et al.*, 1999; Kliukiene *et al.*, 2001). As these women are not sensitive to changes in light, consequently their melatonin levels do not change. These studies showed an approximately 20–50% lower risk of breast cancer among such women compared with general population (Hahn, 1991; Coleman and Reiter, 1992; Verkasalo *et al.*, 1999; Kliukiene *et al.*, 2001). A tendency toward an inverse dose–response relationship between the degree of blindness and breast cancer has been reported (Verkasalo *et al.*, 1999).

In conclusion, our study indicates that occupational exposure to electromagnetic fields increases the risk of breast cancer. The cohort analysis showed an association between work as radio and telegraph operator and risk of breast cancer. The case–control analysis evaluating exposure categories supports a dose–response pattern.

Our results indicated different risk of ER-positive and ER-negative breast cancer by cumulative exposure to EMF in women before and after the age of 50 years. Thus, in future studies menopausal and oestrogen

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receptor status should be taken into account. Future studies should also include large samples in order to detect small to moderate associations and control for well-known breast cancer confounders.

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