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Ecological study on residences in the vicinity of AM radio broadcasting towers and cancer death: preliminary observations in Korea

Received: 11 December 2003 / Accepted: 28 January 2004 / Published online: 31 July 2004
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Abstract Objectives: Public health concern about the health effects of radio-frequency electromagnetic fields (RF-EMFs) has increased with the increase in public exposure. This study was to evaluate some health effect of RF exposure by the AM radio broadcasting towers in Korea. **Methods:** We calculated cancer mortality rates using Korean death certificates over the period of 1994–1995 and population census data in ten RF-exposed areas, defined as regions that included AM radio broadcasting towers of over 100 kW, and in control areas, defined as regions without a radio broadcasting tower inside and at least 2 km away from the towers. **Results:** All cancers-mortality was significantly higher in the exposed areas [direct standardized mortality rate ratio (MRR) = 1.29, 95%CI = 1.12–1.49]. When grouped by each exposed area and by electrical power, MRRs for two sites of 100 kW, one site of 250 kW and one site of 500 kW, for all subjects, and for one site of 100 kW and two sites of 250 kW, for male subjects, showed statistically significant increases without increasing trends according to the groups of electric power. Leukemia mortality was higher in exposed areas (MRR = 1.70, 95% CI = 0.84–3.45), especially among young adults aged under 30 years (0–14 years age group,

MRR = 2.29, 95% CI = 1.05–5.98; 15–29 age group, MRR = 2.44, 95% CI = 1.07–5.24). **Conclusions:** We observed higher mortality rates for all cancers and leukemia in some age groups in the area near the AM radio broadcasting towers. Although these findings do not prove a causal link between cancer and RF exposure from AM radio broadcasting towers, it does suggest that further analytical studies on this topic are needed in Korea.

Keywords Radio-frequency · Broadcasting towers · Neoplasm · Mortality

Introduction

Public health concern about the health effects of electromagnetic fields (EMFs) has increased as public exposure to EMFs has increased. Public exposure to diverse radio-frequency electromagnetic fields (RF-EMFs) has tended to increase steadily in line with the continuous development of new technologies. RF-EMFs are generated by wireless communication systems, as bands of AM/FM radio-frequency: Very high frequency (VHF) and ultra-high frequency (UHF). RF is defined as the EMF of frequencies with the range of 300 Hz–3,000 GHz [1]. RF-EMF resulting from radio and television broadcasting towers has a range of frequencies of between 1,000 kHz and 1,000 MHz.

The thermal effects of high exposure to RF-EMF have been accepted, and a safety guideline for RF exposure has been established. However, the adverse health effects of RF exposure have been the subject of considerable controversy [1, 2]. Experimental investigation suggests that RF fields are not tumor initiators, and that if they are related to carcinogenicity, this would be by tumor promotion or by increased uptake of carcinogens in cells [3]. Few epidemiological studies are available on the use of mobile phones or on RF exposure and the development of cancer. The first types of

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studies were ecological correlation studies that resulted from mortality and/or morbidity associated with proximity to radio and/or television transmitters. Some studies have suggested excess leukemia morbidity and/or mortality rates [4, 5]; however, others have not consistently found such findings [6, 7]. These conflicting results might be caused by ecological fallacy, misclassification of exposure assessment and uncontrolled confounding factors. Others studies involve occupational exposure. A study of a population in Poland that was occupationally exposed to RF or microwaves, showed excess risks of all cancer, cancer of the alimentary tract, brain tumors, and cancers of the hematopoietic system and lymphatic organs [8]. In a cohort of Italian plasticware workers exposed to RF fields generated by dielectric heat sealers, mortality rate from cancers was slightly elevated, and increased risks of leukemia were detected [9]. In a case-control study, an association between occupational RF radiation exposure and uveal melanoma was reported [10]. However, some studies have shown no evidence of elevated cancer deaths or incidence in occupationally exposed workers [11, 12, 13].

During the recent decades, Korea has rapidly developed in the field of wireless communication systems, and public exposure to diverse RF-EMFs has increased. However, the potential adverse effects of RF-EMFs have not been extensively assessed. We performed this study to compare the mortality rates of a population residing within 2 km of a radio broadcasting tower (over 100 kW) with those of a population residing at least 2 km away from such towers, using data from death certificates and population censuses in Korea.

Materials and methods

Addresses on Korean death certificates are described by the governmental administrative unit, such as a small city (Si), a small administrative department in a large city (Ku), and medium-sized rural area (Kun). The exposed areas were chosen by the selection of administrative units (Si, Kun, or Ku) that included the Korean main AM radio broadcasting towers, whose electrical power output was 100 kW or more. Among a total of 107 Korean AM radio broadcasting towers, ten of 100 kW and more were selected. The levels of electrical power were 100 kW in four sites, 250 kW in two sites, 500 kW in three sites and 1,500 kW in one site. All these towers had begun transmission before 1979. The control areas selected were four administrative units that matched to each selected exposed area.

The control areas had similar numbers of people and were located in the same province as the matched exposed area, but they did not contain broadcasting towers and were at least 2 km distant from such towers. When appropriate control areas could not be chosen in the same province, they were selected from the nearest neighboring province.

All deaths due to cancer and death by cancer type were identified in Korean death certificates over the period of 1994–1995. A Korean population census has been performed on November 1st, every 5 years. The 1995 data were collected in accordance with the newly formed administration units (by the law of district rearrangement in 1995). On the other hand, the death certificate data were compiled by the old administration units. Therefore, we established the base population, using the 1990 population census data [14, 15], which were gathered before the district rearrangement.

The study population was selected as the residents in each exposed or control area. We assumed that the resident population in each area during 1994–1995 was equal to that at the time of the Korean nationwide population census of November 1st, 1990, and that all dead persons registered in the death certificate data for 1994–1995, were resident for at least 1 year. To control for possible bias related to the selection of each control area, we selected the four control areas per one exposed area, and each control area was chosen as the site having a similar population number and similar status of socioeconomic indices (e.g., the number of health personnel, regional hospital, school, the structure of industry and occupation) as each exposed area. The total numbers were 1,234,123 and 6,881,783 persons in the exposed area and control area, respectively. From January 1st, 1994 to December 31st, 1995, the number of people who died from various cancers (ICD-9 code 140–208 and 230–238; ICD-10 code C00–C99 and D00–D09) was 97,927, and among these, 97,817 individuals were selected. The cases with wrong addresses were excluded. The number of deaths from cancer was 1,722 for the exposed area and 6,191 for the control area.

We calculated the age-adjusted cancer mortality rates of the two groups in a total of ten exposed areas and 40 control areas, using the direct standardization method used for the standard world population by the World Health Organization (WHO) [16]. For adjusting age, we divided all populations in each area into six age groups (0–14, 15–29, 30–44, 45–59, 60–74, and 75 or more years), and calculated all cancer and specific cancer mortality rates with 95% confidence intervals [17, 18]. They were calculated based on 100,000 subjects annually, and the difference in the mortality rates between the exposed group and the control group was shown by the direct standardized mortality rate ratio (MRR) and its 95% CI using Byar's approximation [17]. By each AM broadcasting site and each group of electrical power, we also calculated MRs in the exposed and control groups and MRRs to see whether the increasing trends were in accord with the electrical power or not.

In the case of four cancers (leukemia: ICD-10 code C90–C95, malignant lymphoma: ICD-10 code C81–C88, brain cancer: ICD-10 code C69–C72, and breast cancer: ICD-10 code C50) that were already suspected of having associations with RF exposure, we calculated the age-specific mortality rates in the exposed and control groups, the age-specific MRRs and their 95% CIs to

compare the two groups. All calculations were carried out by SAS software.

Results

The mortality rates for all cancer were 113.07 per 100,000 persons in the exposed group and 87.32 per 100,000 in the control group. All cancer mortality in the exposed group was 1.29-times higher than the control groups, and this was significant (95% CI=1.12–1.49). The mortality rates for all cancer, by gender, were significantly different in the exposed and control areas for male subjects (male, MRR=1.43, 95% CI=1.29–1.59; female, MRR=1.14, 95% CI=0.92–1.42). However, mortality rates for specific cancer type were not significantly different in the two groups (Tables 1 and 2). The association between mortality rates due to leukemia, malignant lymphoma, brain cancer and breast cancer, and EMF exposure has been suspected in previous other studies; however, these were also not significantly different in the two groups (Tables 1 and 2).

The mortality rates for all cancer in the exposed and control groups, and MRRs between exposed and control group, by electrical power, are shown in Tables 3, 4 and 5. For the total population, the MRRs in areas 1 and 3 (100 kW), area 6 (250 kW), and area 7 (500 kW) were statistically significantly increased. In the electrical power groups of 100 kW and 250 kW, MRRs showed statistically significant increases, although there was no increasing trend according to the electrical power. Among the male population, the MRRs in area 1 (100 kW), area 5 (250 kW), and area 7 (500 kW), showed statistically significant increases, as did those for

the female population in area 6 (250 kW). MRRs for the electrical power groups of 100 kW and 500 kW for male subjects showed significant increases.

The age-specific MRRs, and their 95% CIs, for leukemia, malignant lymphoma, brain cancer and female breast cancer, are shown in Tables 6 and 7. The mortality rate of childhood leukemia in the exposed group was 1.70-times higher than in the control group (95% CI=0.84–3.45). In leukemia, among those under 45 years of age, mortality rates in the exposed group were significantly higher than in the control group (0–14 year age group, MRR=2.29, 95% CI=1.05–5.98; 15–29 year age group, MRR=2.44, 95% CI=1.07–5.24). The MRR for those over 75 years of age was also found to be significant (MRR=3.26, 95% CI=1.07–9.96). In the cases of malignant lymphoma, brain cancer and female breast cancer, no significant differences were found between the exposed and the control groups.

Discussion

Stomach cancer was the most common cause of cancer death among Koreans in 1995, and liver cancer (including that of intra-hepatic duct) was the second most common cause of cancer death. These were followed by lung cancer (including tracheal cancer) and colorectal cancer (including anal cancer) during the study period [19]. The chosen study areas showed the same order of death due to cancer.

In 1999, many broadcasting stations (107 AM radio, 200 FM radio and 1,187 television), wireless transmission facilities (cellular phones), car phones, and radar for civil and military purposes, were operational in Korea. Among

Table 1 Cancer mortality rate per 100,000 persons in the exposed and control groups, for all subjects

Localization	Total				MRR ^b (95% CI)
	Exposed		Controls		
	No. of deaths	MR ^a	No. of deaths	MR ^a	
All cancer	1,722	113.07 (118.47–107.67)	6,191	87.32 (85.14–89.51)	1.29 (1.12–1.49)
Oral cavity and pharynx	14	0.90 (0.42–1.39)	53	0.75 (0.54–0.95)	1.21 (0.41–3.57)
Esophagus	49	3.05 (2.18–3.92)	178	2.53 (2.16–2.91)	1.20 (0.71–2.03)
Stomach	403	25.72 (23.19–28.26)	1559	21.83 (20.74–22.92)	1.18 (0.96–1.44)
Colorectum including anus	78	5.04 (3.90–6.17)	273	3.80 (3.35–4.25)	1.33 (0.83–2.11)
Liver including intrahepatic duct	271	18.17 (15.99–20.36)	1,255	17.98 (16.98–18.98)	1.01 (0.80–1.27)
Pancreas	74	4.38 (3.35–5.40)	215	2.88 (2.49–3.27)	1.52 (0.97–2.39)
Lung including trachea	232	14.59 (12.70–16.49)	964	13.52 (12.66–14.38)	1.08 (0.84–1.38)
Central nervous system including brain	30	2.10 (1.34–2.87)	100	1.39 (1.11–1.66)	1.52 (0.61–3.75)
Thyroid	7	0.46 (0.10–0.82)	25	0.34 (0.20–0.47)	1.35 (0.22–8.19)
Breast	22	1.61 (0.93–2.28)	84	1.17 (0.92–1.42)	1.38 (0.63–3.02)
Leukemia and multiple myeloma	55	4.02 (2.94–5.11)	169	2.36 (2.00–2.72)	1.70 (0.84–3.45)
Lymphatic organs	31	2.11 (1.36–2.86)	96	1.32 (1.05–1.59)	1.60 (0.72–3.56)
Bone and connective tissue	8	0.51 (0.14–0.88)	35	0.49 (0.32–0.65)	1.05 (0.21–5.22)
Urinary bladder	16	0.95 (0.48–1.42)	60	0.84 (0.63–1.05)	1.13 (0.48–2.65)
Prostate	—	—	—	—	—
Uterine cervix	—	—	—	—	—
Skin	8	0.52 (0.15–0.88)	21	0.30 (0.17–0.43)	1.72 (0.36–8.21)

^aAge-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by the WHO

^bCalculated by dividing MR of exposed group (observed) by MR of control group (expected). The 95% CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])

Table 2 Cancer mortality rate per 100,000 persons in the exposed and control groups, by gender

Localization	Male			Female		
	Exposed		MRR ^b (95% CI)	Exposed		MRR ^b (95% CI)
	No. of deaths	MR ^a		No. of deaths	MR ^a	
All cancer	1,115	161.50 (151.96–171.05)	1.43 (1.29–1.59)	607	73.78 (67.74–79.83)	1.14 (0.92–1.41)
Oral cavity and pharynx	11	1.59 (0.62–2.56)	1.37 (0.42–4.49)	3	0.35 (0.00–0.76)	1.11 (0.08–14.87)
Esophagus	43	6.15 (4.30–8.00)	1.35 (0.77–2.37)	6	0.61 (0.09–1.13)	1.23 (0.25–5.92)
Stomach	235	34.24 (29.83–38.65)	1.22 (0.94–1.58)	168	19.16 (16.19–22.12)	1.22 (0.88–1.70)
Colorectum	41	6.05 (4.18–7.91)	1.54 (0.80–2.94)	37	4.31 (2.87–5.74)	1.16 (0.60–2.25)
including anus						
Liver including intrahepatic duct	197	28.62 (24.60–32.64)	1.11 (0.85–1.45)	74	9.05 (6.94–11.16)	0.96 (0.61–1.52)
Pancreas	41	5.59 (3.86–7.32)	1.66 (0.93–2.96)	33	3.26 (2.09–4.44)	1.38 (0.68–2.80)
Lung including trachea	169	24.58 (20.85–28.31)	1.20 (0.90–1.61)	62	6.89 (5.14–8.63)	1.05 (0.64–1.72)
Central nervous system including brain	17	2.54 (1.34–3.76)	1.95 (0.59–6.46)	13	1.77 (0.76–2.78)	1.20 (0.31–4.61)
Thyroid	2	0.24 (0.00–0.63)	0.71 (0.04–13.35)	5	0.68 (0.06–1.29)	2.05 (0.25–17.00)
Breast	1	0.08 (0.00–0.30)	0.07 (0.00–0.16)	21	3.10 (1.78–4.42)	1.26 (0.57–2.77)
Leukemia and multiple myeloma	33	4.87 (3.19–6.55)	1.89 (0.75–4.75)	22	3.26 (1.86–4.66)	1.55 (0.52–4.68)
Lymphatic organs	19	2.63 (1.42–3.83)	1.72 (1.30–2.15)	12	1.68 (0.73–2.63)	1.80 (0.48–6.71)
Bone and connective tissue	6	0.75 (0.12–1.38)	0.58 (0.33–0.83)	2	0.33 (0.00–0.79)	0.80 (0.06–11.14)
Urinary bladder	13	1.82 (0.80–2.84)	1.37 (0.52–3.60)	3	0.40 (0.00–0.83)	1.14 (0.24–2.89)
Prostate	8	1.04 (0.29–1.78)	1.78 (0.55–5.81)	–	–	–
Uterine cervix	–	–	–	26	3.49 (2.13–4.85)	1.34 (0.60–2.97)
Skin	2	0.31 (0.00–0.74)	0.90 (0.08–10.31)	6	0.71 (0.12–1.29)	2.76 (0.31–24.63)

^aAge-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by the WHO^bCalculated by dividing MR of exposed group (observed) by MR of control group (expected). The 95% CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])

Table 3 MRR of all cancers, by each area and by the level of electrical power, for all subjects

Area	Electrical power (kW)	Exposed			Matched control			MRR ^c (95% CI)		
		No.	No. of deaths	CMR ^a (95% CI)	MR ^b (95% CI)	No.	No. of deaths	CMR (95% CI)	MR ^b (95% CI)	MRR ^c (95% CI)
1	100	151,380	231	152.27 (132.62–171.91)	150.43 (130.96–169.91)	944,244	909	96.21 (89.96–102.47)	104.27 (97.46–111.08)	1.44 (1.10–1.89)
2	100	84,847	130	152.63 (126.36–178.90)	111.33 (91.65–131.01)	268,763	401	149.20 (134.61–163.80)	77.35 (69.25–85.47)	1.44 (0.97–2.13)
3	100	56,116	173	307.40 (261.60–353.20)	236.34 (200.11–272.57)	462,122	844	182.53 (170.22–194.83)	173.68 (161.91–185.45)	1.36 (1.00–1.84)
4	100	120,669	282	233.70 (206.45–260.94)	184.04 (162.29–205.79)	454,319	818	180.05 (167.72–192.38)	203.55 (189.50–217.60)	0.90 (0.70–1.17)
5	250	122,586	181	109.66 (93.69–125.62)	78.45 (66.82–90.08)	355,171	408	114.87 (103.73–126.02)	64.21 (57.60–70.82)	1.22 (0.87–1.71)
6	250	100,085	230	229.31 (199.67–258.94)	276.04 (240.05–312.03)	479,816	576	118.80 (109.05–128.54)	158.25 (145.11–171.40)	1.74 (1.33–2.28)
7	500	148,434	111	74.44 (60.57–88.32)	85.91 (69.51–102.32)	2,697,922	672	24.89 (23.01–26.77)	36.97 (34.09–39.84)	2.32 (1.58–3.42)
8	500	187,349	176	93.68 (79.82–107.53)	77.12 (65.59–88.64)	370,420	596	160.76 (147.86–173.79)	118.25 (108.62–127.88)	0.65 (0.48–0.88)
9	500	88,262	97	109.33 (87.53–131.14)	59.39 (46.94–71.84)	356,712	507	142.13 (129.77–154.50)	90.11 (81.98–98.25)	0.66 (0.43–1.01)
10	1,500	131,921	115	86.79 (70.90–102.69)	60.00 (48.80–76.20)	492,294	636	129.19 (119.16–139.23)	82.29 (75.71–88.87)	0.73 (0.50–1.07)
100 kW group		413,012	222	197.21 (183.68–210.74)	163.56 (152.22–174.89)	2,129,448	3,005	141.09 (136.05–146.14)	130.94 (126.24–135.64)	1.25 (1.08–1.45)
250 kW group		265,145	411	154.82 (139.86–169.79)	129.81 (117.15–142.48)	834,987	996	119.22 (111.82–126.63)	96.93 (90.84–103.03)	1.34 (1.08–1.65)
500 kW group		424,045	383	90.20 (81.17–99.24)	74.17 (66.62–81.71)	3,425,054	1,829	53.38 (50.94–55.83)	61.94 (59.08–64.80)	1.20 (0.98–1.47)
1,500 kW group		131,921	115	86.79 (70.90–102.69)	60.00 (48.80–71.20)	492,294	636	129.19 (119.16–139.23)	82.29 (75.71–88.87)	0.73 (0.43–1.24)
All		1,234,123	1,722	139.53 (132.95–146.12)	113.07 (118.47–107.67)	6,881,783	6,191	89.96 (87.72–92.20)	87.32 (85.14–89.51)	1.29 (1.12–1.49)

^aCrude mortality rate per 100,000 persons annually^bAge-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by the WHO^cCalculated by dividing MR of exposed group (observed) by MR of control group (expected). The 95% CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])**Table 4** MRR of all cancers, by each area and by the level of electrical power, for male subjects

Area	Electric power (kW)	Exposed			Matched control			MRR ^c (95% CI)		
		No.	No. of deaths	CMR ^a (95% CI)	MR ^b (95% CI)	No.	No. of deaths	CMR (95% CI)	MR ^b (95% CI)	MRR ^c (95% CI)
1	100	75,562	138	182.63 (152.19–213.08)	222.40 (184.70–260.10)	471,939	524	110.93 (101.43–120.42)	146.00 (133.22–158.79)	1.52 (1.07–2.16)
2	100	41,098	92	223.86 (178.16–269.55)	184.11 (145.88–222.33)	132,454	279	210.26 (185.59–234.93)	121.37 (106.59–136.14)	1.52 (0.98–2.36)
3	100	28,973	119	410.73 (337.09–484.37)	324.97 (260.46–389.48)	250,607	578	230.64 (211.86–249.42)	243.74 (223.75–263.72)	1.33 (0.89–1.99)
4	100	59,790	189	316.11 (271.11–361.10)	289.17 (247.58–330.76)	232,890	547	234.66 (215.01–254.31)	336.16 (307.00–365.32)	0.86 (0.63–1.17)
5	250	82,733	116	140.21 (114.71–165.71)	120.00 (98.04–141.95)	177,515	276	155.20 (136.89–173.51)	101.31 (89.05–113.57)	1.53 (1.04–2.27)
6	250	51,262	143	278.96 (233.30–324.62)	400.57 (333.49–467.64)	247,112	381	153.98 (138.52–169.44)	261.11 (233.74–288.48)	1.18 (0.85–1.64)
7	500	93,170	69	74.06 (56.5902–91.53)	84.05 (63.50–104.60)	1,800,137	777	24.39 (22.11–26.67)	33.93 (30.69–37.16)	2.48 (1.55–3.97)
8	500	94,731	103	108.20 (87.27–129.14)	100.47 (80.98–129.96)	189,623	333	188.27 (168.76–213.90)	157.10 (120.72–173.47)	0.64 (0.43–0.95)
9	500	43,891	64	145.82 (110.12–181.52)	96.69 (72.38–121.00)	178,532	349	195.20 (174.73–215.68)	146.54 (130.92–162.16)	0.66 (0.40–1.09)
10	1,500	66,822	83	123.46 (96.84–150.09)	98.92 (77.40–120.45)	268,487	439	163.32 (148.05–178.60)	109.65 (99.18–120.11)	0.90 (0.58–1.40)
100 kW group		205,423	538	261.90 (239.80–284.00)	249.23 (227.87–270.58)	1,087,890	927	177.09 (169.19–184.99)	192.49 (183.85–201.14)	1.29 (1.08–1.55)
250 kW group		133,995	259	193.29 (169.77–216.81)	193.11 (169.50–216.72)	424,627	656	154.49 (142.68–166.30)	150.94 (139.34–162.54)	1.28 (0.99–1.65)
500 kW group		231,792	236	101.60 (88.63–114.57)	93.46 (81.40–105.52)	2,168,292	1,145	52.78 (49.73–55.84)	65.44 (61.60–69.27)	1.43 (1.11–1.84)
1,500 kW group		66,822	83	123.46 (96.84–150.09)	98.92 (77.39–120.45)	268,487	439	163.32 (148.05–178.60)	109.65 (99.18–120.11)	0.90 (0.58–1.40)
All		638,032	1,115	174.76 (164.51–185.01)	161.50 (151.96–171.05)	3,949,296	4,054	102.65 (99.49–105.81)	112.59 (109.10–116.07)	1.43 (1.29–1.59)

^aCrude mortality rate per 100,000 persons annually^bAge-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by the WHO^cCalculated by dividing MR of exposed group (observed) by MR of control group (expected). The 95% CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])

Table 5 MRR of all cancers, by each area and by the level of electrical power, for female subjects

Area	Electric power Exposed (kW)	Matched control				MRR ^c (95% CI)			
		No.	No. of deaths	CMR ^a (95% CI)	MR ^b (95% CI)	No.	No. of deaths	CMR ^a (95% CI)	MR ^b (95% CI)
1	100	75,818	93	122.00 (97.15–146.85)	105.88 (83.96–127.79)	472,305	204	80.46 (72.37–88.54)	76.03 (68.32–83.74)
2	100	43,749	38	85.72 (58.29–113.14)	58.21 (38.52–77.90)	136,309	123	87.67 (71.96–103.38)	41.93 (33.49–50.38)
3	100	27,143	54	197.10 (144.34–249.87)	155.12 (112.50–197.73)	211,515	307	145.14 (128.92–161.37)	123.89 (109.83–137.95)
4	100	60,879	93	152.76 (121.74–183.79)	111.17 (87.71–134.63)	221,429	272	122.61 (108.04–137.19)	118.59 (104.20–132.97)
5	250	82,327	65	78.95 (59.77–98.14)	46.61 (34.75–58.46)	177,656	120	68.95 (56.75–81.16)	34.31 (27.45–41.17)
6	250	48,823	87	177.17 (139.87–214.48)	185.28 (145.85–224.72)	232,704	217	93.25 (80.85–105.65)	101.33 (87.65–115.01)
7	500	55,264	42	75.09 (52.26–97.93)	96.64 (66.31–126.97)	897,785	279	31.08 (27.43–34.72)	54.91 (47.99–67.82)
8	500	92,618	73	78.82 (60.75–96.89)	60.44 (46.19–79.69)	180,797	247	136.34 (119.33–152.80)	90.96 (73.30–102.63)
9	500	44,371	33	73.25 (48.07–98.42)	33.53 (21.10–45.96)	178,180	159	88.96 (75.11–102.80)	48.90 (40.67–57.14)
10	1,500	65,099	32	49.16 (32.13–66.1834)	28.90 (18.48–49.33)	223,807	380	91.15 (78.65–103.65)	56.09 (47.99–64.19)
100 kW group		207,589	277	133.20 (117.51–148.89)	100.80 (88.61–112.98)	1,041,558	1,078	103.50 (97.32–109.67)	84.93 (79.78–90.08)
250 kW group		131,150	152	115.52 (97.13–133.91)	82.42 (68.95–95.89)	410,360	340	82.73 (73.94–91.53)	57.54 (51.21–63.86)
500 kW group		192,253	147	76.46 (64.11–88.82)	56.83 (47.37–66.29)	1,256,762	684	54.43 (58.50–50.35)	56.84 (52.55–61.13)
1,500 kW group		65,099	116	49.16 (32.13–66.18)	28.90 (18.48–39.33)	223,807	204	91.15 (78.65–103.65)	56.10 (47.99–64.19)
All		596,091	607	101.83 (93.73–109.93)	73.78 (67.74–79.83)	2,932,487	2,249	76.69 (73.52–79.86)	64.83 (62.12–67.54)

^aCrude mortality rate per 100,000 persons annually^bAge-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by the WHO^cCalculated by dividing MR of exposed group (observed) by MR of control group (expected). The 95% CI of MR was estimated from the equation suggested in Fisher [18] and that of MRR was estimated from a logarithmic scale (Breslow and Day [17])**Table 6** Age-specific MR and MRR (95% CI) of leukemia, including multiple myeloma and malignant lymphoma in the exposed and control groups

Age (years)	No. of population		Leukemia				Malignant lymphoma			
	Exposed	Control	Exposed	Control	MR ^a	MRR ^b (95% CI)	Exposed	Control	MR ^a	MRR ^b (95% CI)
			No. of deaths	No. of deaths			No. of deaths	No. of deaths		
Total	1,234,123	6,881,783	55	169	4.02	1.70 (0.84–3.45)	31	96	2.11	1.32
0–14	309,648	1,830,824	11	27	3.31	2.29 (1.05–5.98)	1	2	0.28	0.12
15–29	375,218	2,038,615	11	30	3.60	2.44 (1.07–5.24)	2	7	0.53	0.35
30–44	242,685	1,589,992	9	26	3.63	2.16 (0.95–4.04)	5	14	1.94	1.00
45–59	178,624	870,196	5	31	3.01	0.73 (0.48–2.89)	8	22	4.33	2.46
60–74	101,605	442,853	10	48	9.45	10.81 (0.57–2.78)	13	38	11.72	8.33
75 or over	26,343	109,303	6	7	22.78	3.08 (0.95–6.59)	2	13	6.27	11.36

^aAge-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by WHO^bCalculated by dividing MR of exposed group (observed) by MR of control group (expected). The 95% CI was estimated from a logarithmic scale (Breslow and Day [17])

Table 7 Age-specific mortality rate and MRR (95% CI) of brain tumor and female breast cancer in the exposed and control groups

Age (years)	No. of population		Brain cancer					Female breast cancer				
	Exposed	Controls	Exposed		Control		MRR ^b (95% CI)	Exposed		Control		MRR ^b (95% CI)
			No. of deaths	MR ^a	No. of deaths	MR ^a		No. of deaths	MR ^a	No. of deaths	MR ^a	
Total	1,234,123	6,881,783	30	2.10	100	1.39	1.52 (0.61–3.75)	21	3.10	81	2.46	1.26 (0.57–2.77)
0–14	309,648	1,83,0824	2	1.12	10	0.53	2.12 (0.44–12.06)	0	0.00	0	0.00	–
15–29	375,218	2,038,615	5	1.34	11	0.54	2.47 (0.41–14.01)	1	0.60	1	0.11	5.43 (0.18–161.83)
30–44	242,685	1,589,992	3	1.38	12	0.82	1.68 (0.22–12.95)	7	6.41	23	3.67	1.74 (0.43–7.19)
45–59	178,624	870,196	8	4.11	18	1.97	2.08 (0.54–7.99)	9	10.00	31	7.53	1.33 (0.39–4.54)
60–74	101,605	442,853	9	8.74	38	8.38	1.04 (0.33–3.28)	3	5.66	19	9.05	0.62 (0.10–4.00)
75 or more	26,343	109,303	3	10.29	11	10.72	0.96 (0.13–6.77)	1	5.89	7	9.62	0.61 (0.03–12.26)

^aAge-adjusted mortality rate per 100,000 persons annually, standardized directly by the world standard population proposed by WHO

^bCalculated by dividing MR of exposed group (observed) by MR of control group (expected). The 95% CI was estimated from a logarithmic scale (Breslow and Day [17])

the main AM radio broadcasting tower sites the present study included ten with more than 100kW of electrical power and which had begun transmission at least 15 years before 1979, from the point of cancer death. In this study, leukemia mortality in the exposed group for those aged less than 30 years was significantly higher than in the control group. Some previous studies reported an excess of childhood leukemia in association with proximity to AM/FM radio and television facilities [4, 5], others reported negative association [6, 7, 20]. In the case of leukemia in this paper, however, there was no dose-response or increasing/decreasing trends according to the level of electrical power. Previous studies performed in Great Britain showed an excess cancer incidence or increasing trend of incidences according to the proximity of the towers [5, 6].

Our exposure assessment did not quantify actual exposure status, because individual exposure levels were not measured. Despite this, our finding of the risk to young adults needs to be thoroughly investigated so that we can definitively answer the question of whether this leukemia risk is a result of exposure to RF or whether it is due to other causes, such as exposure from work.

In this study, stomach cancer, the primary cause of Korean cancer death before 2001, was associated with higher mortality in the exposed group, although the MRR did not show a statistically significant increase. In addition, two previous studies reported the risk of gastric cancer in association with EMF exposure [8, 21]. However, these were results of occupational exposure and not of environment exposure. In our study we are unable to prove that RF exposure increases the risk of gastric cancer in Koreans. However, further meaningful research on the relation between gastric cancer and RF exposure is needed in Korea, where the mortality and morbidity rates for gastric cancer in Korea are very high compared with other countries.

Our study has the following limitations. First, the address on the mortality records may not reflect the real address. We obtained the address information from the death certificate, in which the recorded address was the place of death. This might not be the actual house where

the dead person had resided during life. In the Korean culture, most people tend to return to their hometown when they die. However, we do not have the information about how exactly the recorded address on the death certificate and the actual address are matched. This factor might be one of the misclassification biases. Second, the exposed areas were defined as locations within 2 km of AM radio broadcasting towers of 100 kW or more. This location was taken to be the location of the regional government center, and, therefore, the defined exposed area was a little wider than that defined by a 2-km radius. Furthermore, the towers' electrical power was not the same. Some of them were 100 kW, and others 250 kW or 500 kW. But we defined the exposed area as the same 2 km radius from the tower regardless of the electrical power. These might be other misclassification factors. Third, the study was limited in terms of the amount of information about other environmental hazards and our inability to control confounding factors, including the socioeconomic status (SES) of the dead, which was reported as an important factor for leukemia mortality at a young age, since SES is usually associated with survival [22]. Other RF sources (mobile phones, VHF sources, etc.) were not considered. Fourth, because cancer deaths are rare events, the higher death numbers or longer follow-up periods must be considered to increase statistical power. This study was limited in terms of its ability to identify a small risk of RF exposure, because the total population size of each exposed area did not exceed 80,000 people. Finally, since the proportion of physician-diagnosed cause of death in Korean death certificates was 60.0% in 1995 [19], there might be a misclassification of disease. However, there was no definitive evidence of differential misclassification between the exposed group and the control group.

Overall, the main result of this study was the observed higher mortality rate for all cancers and leukemia in the young in the RF-exposed area. Although these findings could not prove a causal link between cancer mortality and exposure to RF fields, the results suggest that further analytical studies on this topic are needed in Korea.

Acknowledgements We would like to thank the Korean Electronics and Telecommunications Research Institute (ETRI) for financial support and the Research Team of EMF Environment in ETRI for their cooperation.

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