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Adult and Childhood Leukemia near a High-Power Radio Station in Rome, Italy

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Some recent epidemiologic studies suggest an association between lymphatic and hematopoietic cancers and residential exposure to high-frequency electromagnetic fields (100 kHz to 300 GHz) generated by radio and television transmitters. Vatican Radio is a very powerful station located in a northern suburb of Rome, Italy. In the 10-km area around the station, with 49,656 residents (in 1991), leukemia mortality among adults (aged >14 years; 40 cases) in 1987–1998 and childhood leukemia incidence (eight cases) in 1987–1999 were evaluated. The risk of childhood leukemia was higher than expected for the distance up to 6 km from the radio station (standardized incidence rate = 2.2, 95% confidence interval: 1.0, 4.1), and there was a significant decline in risk with increasing distance both for male mortality ($p = 0.03$) and for childhood leukemia ($p = 0.036$). The study has limitations because of the small number of cases and the lack of exposure data. Although the study adds evidence of an excess of leukemia in a population living near high-power radio transmitters, no causal implication can be drawn. There is still insufficient scientific knowledge, and new epidemiologic studies are needed to clarify a possible leukemogenic effect of residential exposure to radio frequency radiation. *Am J Epidemiol* 2002;155:1096–103.

child; geography; incidence; leukemia; mortality; radio

Health effects of microwave and radio frequency exposure (10 kHz to 300 GHz) have become a matter of increasing public concern in recent years owing to the growth of telecommunication systems. International guidelines for radio-frequency exposure for the general population (1) have been set to avoid thermal effects because other negative health effects have not yet been documented. The recent revision of these guidelines establishes maximum power flux density ranges of 200–1,000 μW/cm^2 in the frequency range of 10 MHz to 300 GHz as maximum power flux density allowed. Italian law (2) has recently adopted even lower thresholds (100 μW/cm^2 in the range of 3 MHz to 3 GHz and 400 μW/cm^2 in the range of 3–300 GHz) and has established the limit of 20 V/m (measure unit for electric field) for outdoors and 6 V/m for indoors when the exposure is more than 4 hours.

Although there is no conclusive scientific evidence of a causal link between radio frequency and cancer, public awareness about potential carcinogenic effects is growing, and there is an increased demand for epidemiologic investigations in the population residing around transmitters. Despite earlier suggestions of an increased risk of leukemia in populations living near radio television transmitters (3, 4), a recent evaluation of human studies on radio frequency and cancer has concluded that there is no consistent evidence of an effect and that "current epidemiologic evidence justifies further research" (5, p. 166).

The Vatican Radio station, located at the northwest edge of Rome, Italy, is a very powerful station that transmits all over the world. After the concern of the population regarding possible health effects associated with the station, epidemiologic investigations were requested by the regional government. The objective of this study was to evaluate the mortality risk for leukemia among adults and the incidence of childhood leukemia in the population living at increasing distances from the radio station by using a geographic analysis approach.

MATERIALS AND METHODS

Vatican Radio station

The radio station was installed in 1957, in an area that covers 2 km in the direction north/south and 1.5 km in the direction east/west. There are numerous transmitters with different emission directions (three rotating and 28 fixed antennas), different transmission powers (ranging from 5 to 600 kW), and different frequency ranges (nine transmitters for short waves, with frequencies of 4,005–21,850

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Abbreviations: CI, confidence interval; RR, relative risk; SIR, standardized incidence ratio; SMR, standardized mortality ratio.

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kHz, and three transmitters for medium waves, with frequencies of 527–1,611 kHz). International and national programs are transmitted at different hours of the day. More-detailed information is reported on the Vatican Radio website (6).

Electromagnetic field measures within the radio station are not available, and the area is outside Italian jurisdiction. Between 1998 and 2001, a number of measurement campaigns in proximity to the wall of the radio station were performed by regional and national environmental protection agencies. A brief description of the measurement campaigns performed in the area, both indoors and outdoors and at different distances from the radio station, and the highest electric field measures reported are provided in table 1. Most of the measurements were performed within 1 km of the station, and they showed values exceeding both the indoor and the outdoor legal limits. A high value was also observed at a 4-km distance. These measures have several limitations, however. They have been performed to detect values exceeding the legal limits and are inadequate to evaluate population exposure. In the radio station, there are many emission sources of radio frequency, with varying frequency and power of emission, but in most cases, the measurements were performed by using a broad-band instrument and were not able to detect individual sources of emission. Another important problem is the variability of the electromagnetic field produced by the radio station because of the program schedules. Since precise information on schedules and on the transmission directions during the day was not provided by Vatican Radio, the measurements were performed in small time windows at different hours and cannot be considered representative of the 24-hour pattern.

Area and population under study

Figure 1 presents a map of the area of study, including the placement of the different transmitters of the radio station (rotating antenna 1, periodic antenna, rotating antenna 2, directive medium-wave antenna, omnidirectional medium-wave antenna, and rows of fixed antennae). Using a Global Positioning System (Garmin's Global Positioning System III Plus, Garmin International Corporation, Shijr, Taipei County, Taiwan), the geographic coordinates of various points in the enclosure were measured (the only area accessible). The coordinates of each transmitter were then estimated by using a scan of the map and the coordinates of the perimeter. A central point among the antennae was thus determined by using the arithmetic mean of these coordinates. This point was arbitrarily assumed as the point source of emission.

The study area was defined as a 10-km circle centered on this point, covering 316 km^2 and including the municipalities of Anguillara and Formello and part of the municipality of Rome. The total population was 49,656 inhabitants with 9,723 children aged 0–14 years (1991 national census). Population data were available at the census tract level (average, 253 inhabitants per tract).

TABLE 1. Results of some measurements of electric fields performed in the area of the Vatican Radio station, Rome, Italy, 1998–2001

Organization, year (instrument)	Frequency range	Indoor/outdoor	Distance from the radio station (km)	Electric field (V/m)* and highest value at each location
National Agency for Energy and Environment (ENEA), 1998 (holaday, model HI-4416)	Broad band (100 kHz–GHz)	Indoor†	<1 (2 houses)	13.6; 20
National Agency for Energy and Environment (ENEA), 1999 (holaday 4422)	Broad band	Indoor†	≈1 (2 houses)	3.5; 8.0
	Broad band	Indoor†	>4 km (1 house)	1.8
National Environmental Protection Agency (ANPA), 1999 (Wandel-Godlamn-MR300-PMM8053)	Broad band	Indoor‡	≈1 (2 houses)	12.7; 16.1
	Broad band	Outdoor‡	≈1	>20.0
Local health authority (ASL RM/A), 1999 (EM PMM 8051+ spectrometer AVANTEST)	1,530 kHz–9,585 kHz	Indoor‡	≈1 (public building, 1 house)	3.0; 4.6
	1,530 kHz–9,585 kHz	Outdoor‡	<1	8.9
	Broad band	Outdoor‡	≈1	15.0
National Agency for Energy and Environment (ENEA), 2001 (EMI, spectrometer HP8568B, HP85685)	1,531 kHz	Indoor‡	≈3 (1 house)	12.2
	11,630–17,520 kHz	Outdoor‡	<0.5 (sports ground; 3 sites)	30.0; 54.0; 95.0
Regional Environmental Protection Agency (ARPA), 2001 (PMM8053, EP330)	Broad band	Outdoor‡	≈1 (3 sites)	18.4; 22.5; 22.3

* The relation between electric field E (V/m) and power density S (W/m^2) when far-field and plane-wave conditions are satisfied is $S = E^2/377$.

† Twenty-four-hour prolonged measurements.

‡ Spot measurements.

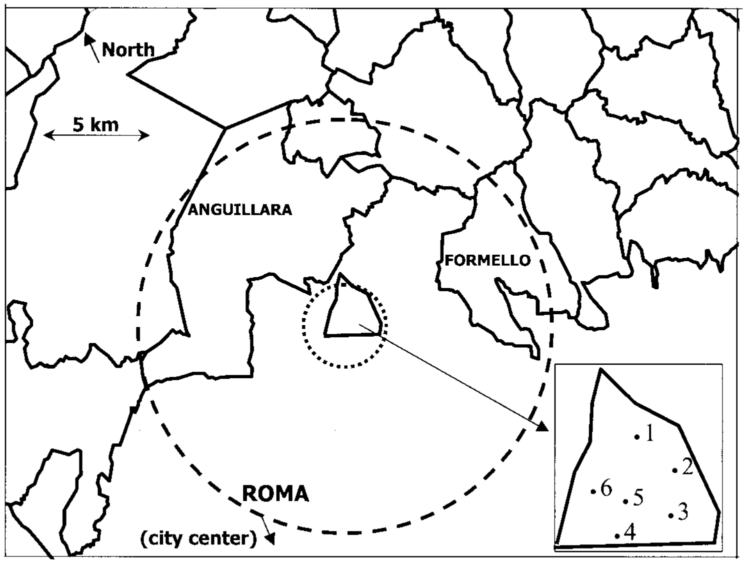

FIGURE 1. Map of the Vatican Radio station, Rome, Italy, 1987–1999. 1, rotating antenna (4,005–21,850 kHz, 200–500 kW); 2, medium-waves directional antennas (527 and 1,530 kHz, 600 kW); 3, medium-waves omnidirectional antennas; 4, rotating antenna (4,005–21,850 kHz, 200–500 kW); 5, log-periodic antenna; 6, fixed antennas. Solid line, municipal boundaries; dotted line, 2-km area; dashed line, 10-km area.

Mortality and incidence data

The source of mortality data was the Lazio Region Geographic Information Mortality System, in which the geographic unit used is the census tract. For each resident, demographic data and underlying cause of death, coded according to the *International Classification of Diseases*, Ninth Revision, are available. We selected all deaths from leukemia (*International Classification of Diseases,* Ninth Revision, codes 2040–2089) among adults (>14 years) that occurred in the study area for all years that were available from 1987 to 1998. Cancer incidence data for adults were not available, since there are no population cancer registries in operation in or near Rome.

Data on childhood leukemia incidence among residents for the period 1987–1999 were provided by the systematic registration through various sources of childhood tumors (tumors in those aged 0–14 years) in Lazio. Since 1989, the Italian Association of Hematology and Pediatric Oncology has collected cases of leukemia diagnosed in associated hospitals. The regional information system on hospital discharges, in activity since 1996, collects information on all of the admissions, and the clinical documentation was reviewed. Clinical information on all childhood cancer cases diagnosed during 1987–1995 at all the main hospitals in Rome were collected directly. The diagnostic accuracy was guaranteed for all cases included, and all cases were confirmed histopathologically. The information regarding residence of all cases was verified through the local population register. In the period 1987–1999, 257 cases of childhood leukemia occurred in Rome. Of these, 75 percent were provided to us through the Italian Association of Hematology and Pediatric Oncology, 12 percent were provided by the system for regional discharges, and 13 percent were found in clinical documents. None of the cases were found exclusively through the death registry. The childhood incidence rate calculated for Rome in 1987–1999 using the above numbers was 60.2 per million per year, while the pooled incidence rate from the Italian Cancer Registries estimated for the overall Italian pediatric population per million was 53.4 for males and 51.4 for females for the period 1988–1992 (7).

The residence of each case at time of diagnosis or death was retrieved from the registry offices and localized by the centroid of the census tract. The distance between the residence of each subject and the radio station was calculated from the central point of the radio station. Since we assumed the site of the radio transmitters to be a single point on the map while the true extension of the station is about 3 km^2, in many cases, the actual distances from the single antennae to the residences may differ from the estimated ones.

Data analysis

A set of five bands with increasing distance from the radio station (2–10 km) was defined, with each band including all census tracts within the defined distance. When a census tract fell in two bands, it was allocated to the band that included the census tract centroid. In each band, observed and expected cases (calculated on the basis of mortality and incidence rates in the municipality of Rome), standardized mortality ratios (SMRs) and standardized incidence ratios (SIRs) (adjusted for a deprivation index) (8) were computed to test for decline in risk of mortality (or incidence) at different distances from the radio station. Adjustment for deprivation index was performed, since socioeconomic status does vary in the study area. However, no significant association was found between socioeconomic condition and leukemia mortality or incidence in Rome. Confidence intervals were based on Poisson likelihood. We used Stone's conditional test (9), first described by Elliott et al. (10), in which a decline in risk of disease with an increase in distance from the source of pollution is tested. This trend-specific test assumes as a null hypothesis that the SMR (or SIR) is constant in each band and equal to the SMR (or SIR) of the entire area under examination (assuming a Poisson distribution for the observed number of cases in each band). The significance level was determined using Monte Carlo simulations.

For evaluation of the robustness of the results, sensitivity analysis was performed on Stone's test results for childhood leukemia under diverse assumptions: collapsing bands with no cases, and excluding childhood cases resident in the same dwelling since birth. Score tests (11) were used to compare different distance-exposure monotonic trends against the null hypothesis of constant risk in all areas. These tests were performed weighing the difference between observed and expected cases with five different functions of distance (inverse distance, inverse square distance, inverse square root of distance, exponential decay, and exponential decay and threshold) (12).

A test for general clustering of childhood leukemia in the Rome metropolitan area was performed to investigate for the presence of spontaneous clusters of disease. The Potthoff-Whittinghill test (13) evaluates the number of pairs of cases, within census tracts, against the null hypothesis of random distribution, taking population density into account. We also used the Scan test (14) to identify potential clusters of cases across census tracts. This test selects the most likely clusters, having drawn all possible circles of all possible radii in the study area. For both tests, Monte Carlo simulations were used.

RESULTS

Table 2 shows the results for leukemia mortality as a function of distance from the radio station. The number of observed deaths in the study period, the SMR (adjusted for deprivation index), and the 95 percent confidence intervals are reported separately for men, women, and both sexes in concentric bands and cumulative areas. A total of 40 deaths of leukemia (21 men and 19 women) were observed in the 10-km area. There was no significant excess of mortality in the different bands and cumulative areas considered, with the exception of male adult mortality within 2 km (Stone's Poisson maximum test, $p = 0.03$). The results of Stone's conditional test are shown in the last row. The test was significant only among men, with a decline in risk as a function of distance after adjustment for deprivation index ($p = 0.03$).

A total of eight childhood leukemia cases (seven lymphatic and one acute nonlymphatic) were observed in the 10-km area (6.5 expected) during the study period (table 3). Table 4 shows observed and expected cases in single bands and cumulative areas around the radio station. SIR values were 6.1 at 0–2 km, 2.3 at 2–4 km, and 1.9 at 4–6 km; no cases were observed in the outer bands (distance >6 km). Observed cases were higher than expected within 6 km (SIR

TABLE 2. Leukemia mortality among adults (aged >14 years) in concentric bands and cumulative areas, Rome, Italy, 1987–1998

Single bands					Cumulative areas			
Distance (km)	OBS†	EXP†	SMR†	95% CI†	Distance (km)	OBS	SMR	95% CI
				Men				
0–2	2	0.7	2.9*	0.5, 9.0	0–2	2	2.9	0.5, 9.0
2–4	6	3.7	1.6	0.6, 3.3	0–4	8	1.8	0.8, 3.4
4–6	7	7.2	1.0	0.4, 1.9	0–6	15	1.3	0.7, 2.1
6–8	5	6.2	0.8	0.3, 1.7	0–8	20	1.1	0.7, 1.7
8–10	1	4.4	0.2	0.0, 1.0	0–10	21	1.0	0.6, 1.4
Stone's conditional test					$p = 0.03$			
				Women				
0–2	0	0.4			0–2	0		
2–4	3	2.3	1.3	0.3, 3.3	0–4	3	1.1	0.3, 2.8
4–6	5	4.7	1.1	0.4, 2.3	0–6	8	1.1	0.5, 2.0
6–8	6	4.1	1.4	0.6, 2.9	0–8	14	1.2	0.7, 1.9
8–10	5	3.6	1.4	0.5, 3.0	0–10	19	1.2	0.8, 1.9
Stone's conditional test					$p = 0.86$			
				Total				
0–2	2	1.1	1.8	0.3, 5.5	0–2	2	1.8	0.3, 5.5
2–4	9	6.0	1.5	0.7, 2.7	0–4	11	1.5	0.8, 2.6
4–6	12	11.9	1.0	0.5, 1.7	0–6	23	1.2	0.8, 1.8
6–8	11	10.4	1.1	0.6, 1.8	0–8	34	1.2	0.8, 1.6
8–10	6	8.0	0.7	0.3, 1.5	0–10	40	1.1	0.8, 1.4
Stone's conditional test					$p = 0.14$			

* Stone's Poisson maximum test, $p = 0.03$.

† OBS, observed cases; EXP, expected cases; SMR, standardized mortality ratio, adjusted for the deprivation index; CI, confidence interval.

TABLE 3. Childhood leukemia incidence within 10 km of the radio station for observed cases, with year of diagnosis, sex, age at diagnosis, type of leukemia, distance from the station, and length of residence in the same dwelling, Rome, Italy, 1987–1999

Year of diagnosis	Sex	Age at diagnosis (years)	Type of leukemia	Distance (km)	Length of residence at diagnosis
1989	Female	2	LL*	4.79	Lifetime
1991	Female	12	ANLL*	3.33	5 years
1993	Male	9	LL	1.37	Lifetime
1996	Male	0	LL	5.56	Lifetime
1997	Male	5	LL	5.79	2 years
1998	Female	7	LL	5.21	Lifetime
1998	Female	1	LL	3.65	Lifetime
1998	Male	4	LL	5.79	Lifetime

* LL, lymphatic leukemia; ANLL, acute nonlymphatic leukemia.

TABLE 4. Incidence of childhood leukemia (0–14 years) among residents in concentric bands and cumulative areas around the radio station in Rome, Italy, 1987–1999

Single bands					Cumulative areas			
Distance (km)	OBS†	EXP†	SIR†	95% CI†	Distance (km)	OBS	SMR	95% CI
0–2	1	0.2	6.1*	0.4, 27.5	0–2	1	6.1	0.4, 27.5
2–4	2	0.9	2.3	0.4, 7.2	0–4	3	2.9	0.7, 7.6
4–6	5	2.6	1.9	0.7, 4.0	0–6	8	2.2	1.0, 4.1
6–8	0	1.7			0–8	8	1.5	0.7, 2.7
8–10	0	1.4			0–10	8	1.2	0.6, 2.3
Stone's conditional test					$p = 0.036$**			

* Stone's Poisson maximum test, $p = 0.02$.
** p value associated with the Stone's conditional test pooling bands at 4–10 km.
† OBS, observed cases; EXP, expected cases; SIR, standardized incidence ratio; CI, confidence interval.

= 2.2, 95 percent confidence interval (CI): 1.0, 4.1) (table 4). Stone's Poisson maximum test showed an excess within 2 km ($p = 0.02$), although it was based on one case only. Stone's conditional test performed across five bands indicated a significant decline in risk with distance from the transmitters ($p = 0.004$); when we considered only three bands, joining the two outer bands without cases to the third one (0–2, 2–4, and 4–10 km), the trend test was still significant ($p = 0.036$) (table 4). In a sensitivity analysis, the results supported the presence of a trend when we excluded the only two cases that had not resided at the same dwelling since birth ($p = 0.057$).

Utilizing Score tests, the significance of different distance functions was evaluated. The results of the tests were significant only for childhood leukemia. The most significant results were obtained for those functions that assigned more weight to the nearest bands: inverse square distance ($z = 2.44$, $p = 0.015$), exponential decay and threshold ($z = 2.39$, $p = 0.017$), inverse distance ($z = 1.68$, $p = 0.093$), exponential decay ($z = 1.68$, $p = 0.093$), and inverse square root of the distance ($z = 1.11$, $p = 0.267$) (figure 2). For male adults, the highest z values were observed for inverse square root of the distance ($z = 1.62$, $p = 0.10$) and exponential decay and threshold ($z = 1.51$, $p = 0.131$).

There was no evidence of clustering of childhood leukemia within and across census tracts in the Rome metropolitan area. The Potthoff-Whittinghill test resulted in a one-sided Monte Carlo p value of 0.786. Only 20 pairs of cases were observed from 257 cases. The Scan test identified only two most likely clusters (five cases over 0.3 expected and eight cases over 1.2 expected; the associated Monte Carlo p values were 0.201 and 0.805), both of which were outside the study area.

DISCUSSION

The results of the study show an excess within 2 km of the radio station and a decline in risk, with distance from the site both for leukemia mortality among male adults and for leukemia incidence among children. However, the number of cases is small, and the excess mortality from leukemia was found only among men, whereas no significant increase was observed among women.

Cancer incidence among residents in proximity to radio and television transmitters has been analyzed in Hawaii (15, 16), Australia (3, 17), and Great Britain (4, 18, 19). In Honolulu, Hawaii, Anderson and Henderson (15) evaluated all cancer and leukemia incidence rates in census tracts encompassing broadcasting towers. An excess of all cancers (45 percent among men and 27 percent among women) and leukemia (58 percent among men and 45 percent among women) was observed in the census tracts where the towers were allocated compared with national rates. Also in Hawaii, Maskarinec et al. (16) conducted a case-control

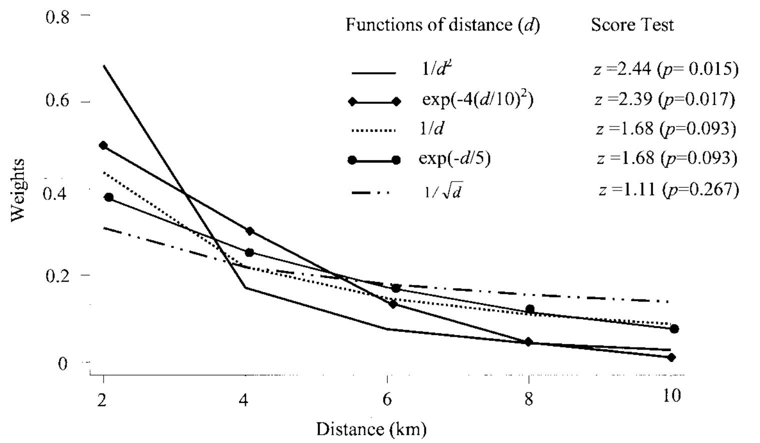

FIGURE 2. Childhood leukemia, different hypothesized patterns of risk with distance from the radio statio, Rome, Italy, 1987–1999. Report of the results of the Score test, which is based on the difference between observed and expected weighted for various distance functions.

study among children in the small communities of the Waianae Coast, where radio towers were present, and an unusual number of children with leukemia was observed (12 cases occurred from 1977 to 1990). The relative risk of leukemia for children living within 2.6 miles of radio towers was 2.0 (95 percent CI: 0.06, 8.3). In recent years, three studies (one from Australia and two from United Kingdom) have been published. In Australia, Hocking et al. (3) analyzed cancer incidence and mortality in three neighboring municipalities, including a group of television towers. A higher risk was observed for childhood leukemia in children living within 4 km of the tower (incidence: relative risk (RR) = 1.58, 95 percent CI: 1.07, 2.34; mortality: RR = 2.32, 95 percent CI: 1.35, 4.01). The same data have been reanalyzed in a more recent study (17), and a weak association between childhood leukemia and radio frequency exposure was found. The results were highly due to one single area included in the study Lane Cover, which presented high levels of exposure and a high leukemia incidence. It was reported that in this area the leukemia rate (for children, 0–14 years) was elevated previous (1972–1978) to the onset of 24-hour television transmissions (1977–1978). Still, at least three stations had been in operation at Lane Cover from 1958 onward (3).

In England, Dolk et al. (4) investigated the incidence of various types of cancer in the population living near the television and radio transmitter of Sutton Coldfield (from 1974 to 1986). The risk for leukemia among adults within 2 km was 1.83 (95 percent CI: 1.22, 2.74), based on 23 observed and 12.6 expected cases, and there was a significant decline in risk with distance from the transmitter ($p = 0.001$). The same authors extended their study to the population living within 10 km of 20 radio and television transmitters in Britain (18) with a minimum power of 500 kW for television and 250 kW for radio transmitters. The increased risk found in the Sutton Coldfield study was not observed in this second study: the observed-to-expected ratio for leukemia among adults was 0.97 within 2 km from the transmitters. The study showed a significant decrease of risk with distance only for leukemia incidence (>15 years). The highest risk was found between 2 and 3 km (RR = 1.15). In particular, it was the densely populated area of Crystal Palace near London, England, that relevantly contributed to the overall results with a relative risk of 1.33 in the 2- to 3-km band. In a recent replication of the analysis around Sutton Coldfield, using more timely cancer data (19), the previous results were not replicated. In the report, evidence was found for a declining risk with distance from the source for all male childhood leukemia (Stone's conditional test, $p = 0.037$) but not for adult leukemia. Observed-to-expected ratios showed a slight increase in risk over the entire study area, but not within 2 km of the transmitter.

Reviews published on this subject (5, 20–25) agree that the studies carried out until now have not allowed advancement of final conclusions because of the heterogeneity of the study design, the difficulty of evaluating exposure, and the small size of the study populations. Moreover, there is no convincing evidence from experimental studies (26) on a possible biologic mechanism to support a leukemogenic effect from nonionizing radiation in the radio frequency range.

Several limitations of our study should be considered. In our analyses, exposure was based on distance from the place of residence and the radio station, since measures of exposure to radio frequency were not available. Measurement campaigns in the area were not conducted systematically, and there is no detailed information about exposure levels of the population or about how electromagnetic fields vary at increasing distance from the transmitters. Measurement campaigns in the area are important, but precise information on schedules and on the transmission directions during the day is essential to obtain reliable results. Moreover, schedules and pattern of transmissions for the past should be available for retrospective estimates. Stone's test for trend assumes a radial distribution of the electromagnetic field, while the spatial pattern of the exposure in presence of many transmitters is surely much more complex and could vary at different angles. Finally, we analyzed a rare exposure and a rare disease in a small population, and consequently, the power of study is low. Although we have considered 13 years of observation, the number of cases observed is still small, and we cannot exclude the possibility that the cluster of cases and the decline in risk observed are, in fact, chance findings.

It has been suggested that children can be expected to be more vulnerable to radio frequency exposure due to the characteristics of their immune system, whose efficacy could be degraded by this radiation (27). However, although the number of known risk factors for childhood leukemia is limited, we do not have individual information on potential confounders (28). We were able to adjust only for a small-area socioeconomic index, as a proxy of socioeconomic status, and the results did not change. Despite possible limits, the results of the study arise from a test with an a priori hypothesis rather than being the outcome of a "search for clusters." The sensitivity analysis indicates that the results are statistically robust. Moreover, the findings for childhood leukemia are remarkably similar (proximity to the radio and decline in risk with increasing distance) to what has been observed for male adult leukemia mortality. Alternative explanations, such as mixing of populations (29) or general clustering of the disease, are unlikely in our data. The results are stable when cases not resident since birth we excluded. Moreover, no leukemia clustering was present in the Rome metropolitan area.

This study is a new independent observation of an excess of leukemia cases in a population living near high-power ratio transmitters. However, our findings, along with previous results from similar studies, do not yield conclusive evidence of a causal association between residential exposure to radio frequency and increase in leukemia incidence. The scientific knowledge on this topic is still limited, but the possibility of an effect cannot be excluded with certainty. Repacholi (30) and Rothman (31), in their revisions on the health effect of radio frequency, underlined the difficulties of epidemiologic studies of populations with residential exposure and concluded that cancer incidence in exposed populations should be investigated further. Populations living in areas with high-power broadcasting transmitters, such as Vatican Radio and Sutton Coldfield transmitter, should be monitored in the future to clarify a possible leukemogenic effect of radio frequency radiation.

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