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The effect of continuous low intensity exposure to electromagnetic fields from Radio Base Stations to cancer mortality in Brazil

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Abstract: Background. This study aims to estimate the rate of death by cancer, according to Radio Base Stations (RBS) radiofrequency exposure, especially for the types of breast, cervix, lung and esophagus cancer. Methods. We collected information about the number of deaths by cancer, gender, age group, Gross Domestic Product per capita, death year and the amount of exposure over the lifetime. We investigated all cancer types and some specific types (breast, cervix, lung and esophagus cancers). Results. In capitals where RBS radiofrequency exposure was higher than 2,000/antennas-year, the average mortality rate was 112/100,000 for all cancers. The adjusted analysis showed that the higher the exposure to RBS radiofrequency, the higher cancer mortality. The highest adjusted risk was observed for cervix cancer (Rate Ratio = 2.18). The spatial analysis showed that the highest RBS radiofrequency exposure was observed in a city in southern Brazil, which also showed the highest mortality rate for all types of cancer and specifically for lung and breast cancer. Conclusion. The balance of our results indicates that the exposure to radiofrequency electromagnetic fields from RBS increases the rate of death by all types of cancer.

Keywords: Cancer; Mortality; Electromagnetic Fields; Breast Neoplasms; Lung Neoplasms; Esophageal Neoplasms; Uterine Cervical Neoplasms

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Background

Mobile phones have become extremely common in modern times. Wireless technology has a large number of Radio Base Stations (RBS), which transmit the information through radiofrequency signals. In 2006, there were already more than 1.4 million RBS in the world [1]. In the Brazilian capitals, RBS begins to be implemented in1992, in Brasília (capital of Brazil) and until 2017, there were 27,145 RBS indexed in the capitals [2].

The effect of electromagnetic fields emanating from RBS on health is not very well known. The World Health Organization (WHO) reported, in 2006, that scientific knowledge had indicated that RBS radiofrequency exposure would be within the international standards and, therefore, it would not pose a risk to human health [1]. However, in 2014, WHO recognizes the need to promote research to investigate the effect of the radiofrequency field on human health as a priority, in order to fill the knowledge gaps [3]. Several issues relating to new wireless technologies are currently highlighted: the environmental impact of RBS radio frequency exposure, its effects on human health, thermal effects and its noise emission [4].

In Brazil, the National Telecommunications Agency (ANATEL) is the entity that regulates the electromagnetic emission of RBS, in accordance with the limits established by Resolution No. 700, of September 28, 2018 (Union Official Diary) [5]. In addition to ANATEL, telecommunication antenna installations are also regulated by municipal laws, in order to minimize environmental and human health impacts [4].

The mobile phone-derived electromagnetic fields are classified by the International Agency for Research on Cancer as possibly carcinogenic to humans [3,6,7]. The intensity of the RBS radiofrequency fields is higher near the antenna and decreases as the distance from it is greater [1,8]. In big cities, however, RBS are located very close to populated areas, above or between homes and businesses. The antennas are so close to homes, that the multi-story windows of residential buildings, for example, are side by side with these antennas [9].

Despite the scarce knowledge on this subject, there are few resources allocated to investigating the role of exposure to electromagnetic fields from RBS on human health. In the United States, for example, until 2010, no funding had been reserved by government agencies to study the possible health effects on people living near RBS [9]. This study aims to estimate the rate of death by cancer, according to RBS radiofrequency exposure, especially by breast, cervix, lung and esophagus cancer.

Methods

This is an ecological study using capitals as the unit of analysis. We collected information about the number of deaths by cancer per gender, age group, Gross Domestic Product per capita (GDP), death year and the amount of exposure over the lifetime.

Information about deaths by cancer per gender and age was collected from the Mortality National System (SIM) from DATASUS website [10]. We investigated all cancer types and some specific types: 1) deaths by breast cancer (International Classification of Diseases 10th Revision (ICD10) Group - Malignant Breast Neoplasms); 2) deaths by cervix cancer (C54 Category of ICD10 - Malignant neoplasm of cervix); 3) deaths by lung cancer (C34 Category of ICD10 - Malignant Neoplasms of the Bronchi and Lungs); and 4) deaths by esophageal cancer (C15 Category of ICD10 - Malignant neoplasm of esophagus).

Census population data [11] and GDP was also collected from DATASUS website [10]. The number of RBS and the year they were implemented in each capital was collected from Telecommunication Service System [2].

People's exposure time was calculated according to the birth and death year. The annual RBS radiofrequency exposure was calculated by sum of the number of RBS implemented in each year,

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multiplied by the people's exposure time. The total exposure was calculated from the sum of annual exposures.

A map with charts was built using the mortality rate per square kilometer (km^2) and the median of RBS radiofrequency exposure, in 2010-2017 period.

Statistical analysis

We calculate the median and interquartile range of mortality rate per 100,000, according to the levels of explanatory variables. Kruskal Wallis test was used to access the statistical differences between groups.

Multilevel Poisson regression models were used to estimate the risk-adjusted mortality. The response variable was death by cancer and the fixed effects were the logarithm transformation of RBS radiofrequency exposure, gender, age group, death year. We also included an offset with the logarithm of population size. The random effects included capital city (intercept), square root transformation of GDP (slope) and capital's area per km^2 (slope). When the response variables were death by breast and cervix cancer, the gender was not included as a fixed effect, as only females were investigated.

The above-mentioned logarithmic transformations and the square root transformation were used to normalize the distribution of variables. We used R-Project version 3.6.1 and ArcGis version 10.5 to perform the analysis.

Results

Both for all cancers and the specific types investigated (breast, cervix, lung and esophagus cancers), the higher the exposure to RBS radiofrequency, the higher the median of mortality rate. In capitals where RBS radiofrequency exposure was higher than 2,000/antennas-year, the median of breast cancer mortality rate was 27.33/100,000, while for all cancers, it was 111.68/100,000 (Table 1).

Table 1. Descriptive analysis of cancer mortality in Brazilian capitals

	Breast	**Cervix**	**Lung**	**Esophagus**	**All cancers**
	Median/10^5	Median/10^5	Median/10^5	Median/10^5	Median/10^5
RBS - sign	***	***	***	***	***
≤500	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	7.30 (44.94)
501-1000	1.16 (27.11)	2.74 (26.30)	0.00 (38.97)	0.00 (0.00)	26.32 (382.14)
1001-2000	20.12 (54.53)	7.38 (25.79)	4.47 (63.42)	0.00 (8.74)	71.95 (500.43)
>2000	27.33 (63.06)	9.56 (16.43)	9.58 (76.46)	1.62 (14.21)	111.68 (552.78)
Sex - sign			***	***	***
Female			3.77 (46.88)	0.00 (3.17)	75.31 (360.87)
Male			4.31 (98.82)	0.45 (22.06)	56.49 (540.97)
Age group - sign	***	***	***	***	***
< 30	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	5.75 (4.53)
30-49	9.89 (13.56)	6.75 (7.31)	1.81 (4.39)	0.00 (1.13)	38.59 (44.90)

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50-69	43.43 (20.19)	15.02 (14.71)	34.08 (42.50)	6.75 (16.28)	258.79 (240.76)
≥60	91.18 (64.51)	27.35 (37.02)	159.40 (159.63)	20.31 (39.68)	1178.11 (1012.72)
Year - sign	NS	NS	NS	NS	NS
2010-2011	16.95 (52.66)	6.29 (19.36)	4.44 (64.91)	0.00 (8.87)	68.76 (508.70)
2012-2013	15.98 (56.94)	6.42 (19.09)	4.13 (66.30)	0.00 (10.29)	65.09 (501.19)
2014-2015	17.36 (56.05)	8.29 (19.52)	4.13 (65.15)	0.00 (9.54)	65.56 (491.10)
2016-2017	18.01 (52.08)	7.62 (16.66)	3.54 (65.52)	0.00 (8.22)	61.87 (444.41)

RBS = exposure to Radio Base Station (antennas-year); Sign = statistical significance - Significance. codes: *** p-value < 0.001; ** p-value < 0.01; * p-value < 0.05; NS p-value > 0.05

Females showed the highest median of mortality rate for all cancers, however, specifically for lung and esophagus cancers, the highest median of mortality rate was observed in male people (4.31/100,000 and 0.45/100,000, respectively) (Table 1).

Both for all cancers and the specific types investigated, the higher the age group, the higher the median of mortality rate. Lung and breast cancers showed high medians of mortality rate (159.40/100,000 and 91.18/100,000, respectively) (Table 1).

The median of mortality rate for all types of cancer decreased from 68.76/100,000 to 61.87/100,000, over the period. As for breast, cervix, lung and esophagus cancers, it showed slight variations, over the period, around 17/100,000, 7/100,000, 4/100,000 and lower than one per 100,000, respectively (Table 1).

In the adjusted analysis, the results showed that the higher the logarithm of RBS radiofrequency exposure, the higher cancer mortality rate. The highest adjusted risk was observed for cervix cancer (Rate Ratio (RR) = 2.18) (Table 2).

Table 2. Adjusted risk of cancer mortality in Brazilian capitals

	Breast		**Cervix**		**Lung**		**Esophagus**		**All cancers**	
	RR	Sign	RR	Sign	RR	Sign	RR	Sign	RR	Sign
Fixed effects										
Log RBS	1.25	***	2.18	***	1.14	***	1.18	**	1.15	***
Sex										
Female					1.00		1.00		1.00	
Male					1.97	***	4.88	***	1.42	***
Age group										
< 30	1.00		1.00		1.00		1.00		1.00	
30-49	37.59	***	13.82	***	20.11	***	73.84	***	6.06	***

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50-69	132.29	***	30.74	***	323.80	***	876.50	***	40.73	***
≥60	297.55	***	53.88	***	1250.63	***	2154.44	***	164.61	***
Year										
2010-2011	1.00		1.00		1.00		0.00		1.00	
2012-2013	0.97	NS	0.78	***	0.97	NS	0.96	NS	0.98	*
2014-2015	0.96	NS	0.62	***	0.93	**	0.88	***	0.95	***
2016-2017	0.81	**	0.46	***	0.84	***	0.76	***	0.84	***
Random effects										
	Std Dev				Std Dev		Std Dev		Std Dev	
Capital (intercept)	0.61	***	1.55	***	0.19	***	0.86	***	0.28	***
Sqrt GDP (slope)	0.00	***	0.01	***	0.00	***	0.00	***	0.00	***
Area/Km² (slope)	0.00	NS	0.00	NS	0.00	NS	0.00	*	0.00	NS
Deviance	12274		8345		24732		10364		100918	

Sqrt GDP = Square root transformation of Gross Domestic Product per capita; RR = Rate Ratio; Std Dev = Standard Deviation; Log RBS = logarithm transformation of Radio Base Station radiofrequency exposure (RBS radiofrequency exposure = sum of the number of RBS in each year multiplied by the exposure time); Sign = statistical significance - Significance. codes: *** p-value < 0.001; ** p-value < 0.01; * p-value < 0.05; NS p-value > 0.05

Multilevel Poisson model was used to estimate the risk of cancer mortality. Except for breast and cervix cancers, which were estimated only for women, every adjusted models included as fixed effects the variables sex, logarithm of RBS, age group and death year. The variables included as random effects were capital (intercept), GDP (slope) and area/Km² (slope). The offset of the population was also included in the models.

Males showed the highest adjusted risk of lung, esophagus and all types of cancer (Table 2), although the median of mortality rate for all cancers have been higher for females in the bivariate analysis (results showed in Table 1).

As expected, there was an increasing trend in the adjusted risk of cancer mortality the older the age group. Compared to people younger than 30 years old, the adjusted risk was 297.55, 53.88, 1,250.63, 2,154.44 and 164.61 for breast, cervix, lung, esophagus cancer and all cancers, respectively (Table 2).

For cervix cancer and all types of cancers, there was a decreasing trend of the adjusted risk of cancer mortality the more recent the period. For lung and esophagus cancers, this trend is observed from 2014-2015 period (Table 2).

The inclusion of random effects was significant in every models for the following effects: "capital" (intercept) and "square root of GDP" (slope). However, for the "area of the capital" (slope) it was

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significant only for esophagus cancer. For all models, the greatest magnitude of the standard deviation of random effects was observed for the "capital" (intercept) (Table 2).

The spatial descriptive analysis showed that the highest median of RBS radiofrequency exposure was observed in Florianópolis (South of Brazil) (44.23 antennas-year/km²). Florianópolis also has the highest mortality rate per km² for all types of cancer and specifically for lung and breast cancer. (0.09/100,000, 0.31/100,000 and 0.93/100,000, respectively). Recife (Northeast) and Belo Horizonte (Southeast) showed a median of RBS radiofrequency exposure higher than 20 antennas-year/km² and their mortality rate per km² for all cancers were 0.29/100,000 and 0.19/100,000, respectively. Vitoria (Southeast), Teresina, Fortaleza, Natal and Aracaju (both in Northeast) showed a median of RBS radiofrequency exposure higher than 10 antennas-year/km² and mortality rate per km² for all types of cancer 0.60/100,000, 0.49/100,000, 0.21/100,000, 0.35/100,000 and 0.38/100,000, respectively (Figure 1).

Figure 1. Distribution of cancer mortality rate in each capital and their experience of exposure to Radio Base Stations radiofrequency, 2010-2017

RBS = Median of Radio Base Station radiofrequency exposure (RBS radiofrequency exposure = sum of the number of RBS in each year multiplied by the exposure time).

We used the median of mortality rate.

Discussion

The evidence on radiofrequency radiation carcinogenesis has increased, since 2011. This study detected an increase in the rate of death by cancer in capitals where there is a greater exposure to electromagnetic fields emanating from Radio Base Stations. Studies made in Stockholm (Sweden) indicate that high levels of environmental radiofrequency radiation are quite present in residential and commercial areas [12-14]. In the United Kingdom, at the beginning of 2009, there were 51,300 RBS and two thirds were installed in existing buildings or other structures [9].

Dode et al., 2011, pointed that electromagnetic fields from telecommunication system is an important environmental problem, nowadays [8]. The authors detected 6,724 deaths by neoplasia occurring within an area of 500 meters from the RBS and 320 deaths within an area between 500 and 1000 meters. The mortality rate within an area of 500 meters was 34.76 per 10,000 inhabitants, while within an area of 1.000 meters, the rate was 32.78 [8].

Although, in the present study, we investigate all cancers, we also investigated breast, cervix, lung and esophagus cancers, separately. In a mortality study performed in Brazil, breast and lung cancers were among the main cancers related to radiofrequency electromagnetic fields from RBS radiofrequency exposure [8].

In the present study, we detected that the higher the exposure to radiofrequency electromagnetic fields from RBS the higher cancer mortality. A study conducted in Israel has also found that low-frequency electromagnetic fields contribute to the breast cancer development [15-17]. Others studies also referred the relationship between cancer and radiofrequency electromagnetic fields [18,19], including in animal studies [20].

In the present study, a capital located in the South showed the highest RBS radiofrequency exposure and the highest mortality by cancer (Florianópolis). In fact, others studies have also reported high rates of cancer in this capital [21-25].

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Our results showed that, in general, men had a higher mortality rate of esophageal and lung cancer and that this rate increases with age. In fact, the scientific literature corroborates these results [26-30].

In order to keep the cellular sets running, the radiofrequency transmitters installed at the tops, roofs, façades of buildings and residences emit electrical and magnetic fields 24 hours a day. However, it is known by scientific knowledge that the non-thermal magnetic component can penetrate deeper into the body than the electrical one [31].

A person can stand at a fixed distance of an RBS and be exposed to 100% of the Maximum Permissible Exposure or 5% of it, depending on the antenna height and the bystander altitude. So, people living in the upper floors of a building located in front of the antennas receive radiofrequency corresponding to 100% of Maximum Permissible Exposure [32]. That data was confirmed in the Post-Graduation Project conducted at Federal University of Minas Gerais (UFMG), Brazil, based in measures made in the capital of the state inside 400 residences located near the RBS, from 2015 to 2019. Measurements made by "MRE Engenharia - Medição de Radiações Eletromagnéticas" [33].

The measured values of the electrical and magnetic fields have shown more human exposure to the electromagnetic radiations in an area within 500 meter-radius from the Transmitter Antennas of Cellular Telephony [8]. To avoid hazards to human health, the safest solution would be to switch off the RBS in an area within a 500-meter radius of distance from residences, workplaces, hospital areas, kindergartens and buildings.

As a limitation, it is important to note that this study used cancer data from national Brazilian sources, which can provide underestimated rates in different levels, according to the region. For example, a study conducted in northern Brazil found a large proportion of deaths classified as unspecified uterine cancer. After the proportional redistribution of these deaths, there was an increase of 46% in the average cervical cancer mortality rates [34]. Another study conducted in Northeastern Region of Brazil, highlights that within the older age group , the number of deaths before and after correction showed a significant variation, especially for breast cancer, where variation reached 54% [35].

Still as limitations of the study, we highlight two more points. In the present study, possible migratory movements were not considered to calculate the amount of exposure to RBS radiofrequency over the lifetime in resident population. This was calculated only according to birth, death year and the year, in which RBS was implemented. However, people could have been born in another city and then migrated to the capital where the death was recorded. The other point is the proximity of stations to places of residence that interfere with the level of exposure of individuals. As it is an ecological study, whose unit of analysis is the capital, this study did not take into account the distances between stations and homes.

Conclusion

The balance of our results indicates that the exposure to radiofrequency electromagnetic fields from RBS increases the rate of mortality by all cancers and specifically by breast, cervix, lung and esophageal cancers. These conclusions are based on the fact that the findings of this study indicate that the higher RBS radiofrequency exposure, the higher cancer mortality rate, especially for cervix cancer (Adjust RR = 2.18). The spatial analysis showed that the highest RBS radiofrequency exposure was observed in a city located southern of Brazil, which also showed the highest mortality rate for all types of cancer and specifically for lung and breast cancer.

Environmental pollution caused by non-ionizing electromagnetic fields increases continuously. The location of RBS is still a controversial field as regards their regulation. There are numerous RBS installed in residential areas, including on their roofs. Some epidemiological studies indicate an increased risk of cancer close to RBS. It is important that further epidemiological investigations are conducted to elucidate the role of the environment towards radiofrequency signals on carcinogenesis process.

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Acknowledgements

We thank Maria Alexandra Araujo Monteiro de Carvalho for the translation work.

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