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Cancer cluster among young Indian adults living near power transmission lines in Bom Jesus do Tocantins, Pará, Brazil

Agrupação de casos de câncer em adultos jovens indígenas residindo nas proximidades de linhas de transmissão de alta tensão elétrica em Bom Jesus do Tocantins, Pará, Brasil

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Abstract A case study was carried out to explore the occurrence of a cancer cluster in 1992 among young Indian adults living in an Amazonian village near two 500 kV power transmission lines that began operating a decade ago. Current blood levels of DDT and organophosphorus pesticides and metal levels in hair samples were measured. Extremely low magnetic field exposure was determined during current daily activities carried out by the Indian villagers. Taking into account the cancer incidence rates in different Brazilian cities, the probability of the occurrence of this cluster by chance was considered remote ($p < 0.003$, Poisson distribution). High blood levels of *p,p'*-DDT (median levels ranging from 26 to 58 ppb) were observed. As a whole, this community showed a pattern of low exposure to organophosphorus pesticides, and high recent exposure was only observed in a few blood samples. Continuous exposure to extremely low electromagnetic fields originated in the power transmission lines (which reached 95.0 mG under the lines) was observed on several opportunities during daily activities carried out by Indian villagers. Further observational studies should evaluate the interaction between exposure to extremely low electromagnetic fields and prior exposure to tumor initiators in cancer development.

Key words Neoplasms; DDT; Pesticides; Electromagnetic Fields; South American Indians

Resumo Um estudo de caso foi desenvolvido para avaliar a ocorrência de um agrupamento de casos de câncer em 1992, que se verificou em adultos jovens indígenas vivendo em aldeia na Amazônia, situada nas proximidades de duas linhas de transmissão de 500 kV, as quais começaram a operar em 1982. Determinaram-se os níveis sanguíneos atuais de DDT e pesticidas organofosforados, assim como a presença de metais em amostras de cabelo. A exposição a campos eletromagnéticos de frequência extremamente baixa foi determinada durante diversas atividades diárias desenvolvidas pelos indígenas. Considerando-se a incidência de câncer em diferentes cidades brasileiras, a probabilidade de ocorrência ao acaso deste agrupamento de casos foi considerada remota ($p < 0,03$, distribuição de Poisson). Níveis elevados de *p,p'*-DDT (mediana variando entre 26 e 58 ppb) foram observados nas amostras estudadas. A exposição contínua aos campos eletromagnéticos de frequência extremamente baixa, a qual atingiu 95 mG abaixo das linhas de transmissão, foi observada em diversas oportunidades durante atividades diárias desenvolvidas pelos indígenas. Estudos observacionais futuros deveriam analisar a interação da exposição aos campos eletromagnéticos de frequência extremamente baixa (50-60 Hz) subseqüente à exposição a agentes de iniciação tumoral no desenvolvimento de neoplasias.

Palavras-chave Neoplasias; DDT; Praguicidas; Campos Eletromagnéticos; Índios Sul-Americanos

Introduction

The occurrence of cancer among Brazilian Indian nations has been scarcely reported in the literature. An active search of cancer cases during an exploratory survey carried out in the late 1950s in several Indian settlements in Brazil failed to observe any cancer cases (Campos, 1961). Since then, mortality from sporadic cases of cancer at different anatomic sites has been mentioned by FUNAI, the Brazilian government agency for Indian affairs (unpublished data).

Parkatêjê Indians ("the people who live on the southern bank of the river" in the Gê-Timbira language, or "Gavião", the Brazilian nickname meaning "Hawk" in Portuguese) have been living since the mid-1970s in the Mãe-Maria Indian Area (MMIA), in the Brazilian Eastern Amazon Region (Figure 1). Three main communities of this Indian nation, formerly living in different geographical areas, were forced to resettle together following mandatory relocation by government authorities in the late 1960s. Relocation was thus enforced and justified by the government as a measure to allow for the development of new large-scale engineering projects, such as a long highway crossing the Amazon jungle (the Transamazonian Highway) and the Tucuruí Hydroelectric Plant in the State of Pará. Since then, and facing virtual extinction as a consequence of severe malnutrition and widespread dissemination of infectious diseases, the Parkatêjê Indians have been attempting to expand their population by stimulating an increase in their birth rate. They have been relatively successful in this attempt and had 306 inhabitants living in the MMIA in 1992.

Cancer was unknown among Parkatêjê Indians until 1992, when a cluster of three cases was reported in their village (Vieira Filho, 1994). The cases were a 22-year-old man with acute lymphoblastic leukemia, a 20-year-old woman with leiomyosarcoma, and a 55-year-old woman with uterine cervical cancer, all of whom with histopathological confirmation.

The occurrence of these cancer cases raised great discomfort among the Parkatêjê Indians, considering both the previous absence of cancer reports in the community and their uncomfortable and distrustful past experience with Brazilian society. Even after undesired resettlement in MMIA, the community was virtually forced to allow the construction of a railway and two power transmission lines crossing their lands (Figure 2). Moreover, the preserved rain forest in MMIA lands, a green island in the

middle of a devastated area of cattle farms, is routinely invaded illegally by woodcutters, creating permanent tension with the Parkatêjê. Thus, the outcome of these cancer cases was almost immediately interpreted by the Parkatêjê as associated to new environmental pollutants introduced through this conflictive contact with the Brazilian society.

In addition, severe ethical concerns were raised following the outbreak of cancer cases (related, for instance, to medical procedures such as the leg amputation once suggested for the young mother with soft tissue sarcoma). A broad discussion thus began surrounding the events possibly associated with these new cancer cases; a search began for different exposures recently introduced into their environment and potentially related to these cancer cases. They included exposure to extremely low electromagnetic fields (EMF) originating from two 500 kV transmission lines crossing the MMIA and starting operations in 1982, a matter of great concern among the Parkatêjê. Other risk factors such as pesticides (never used by the Parkatêjê but widely employed in farms surrounding the MMIA) were also suspected.

This paper presents the conclusions of a technical report prepared by a interdisciplinary team which conducted an epidemiological case study trying to evaluate the impact of different environmental exposures possibly associated with the aforementioned cancer cluster.

Methods

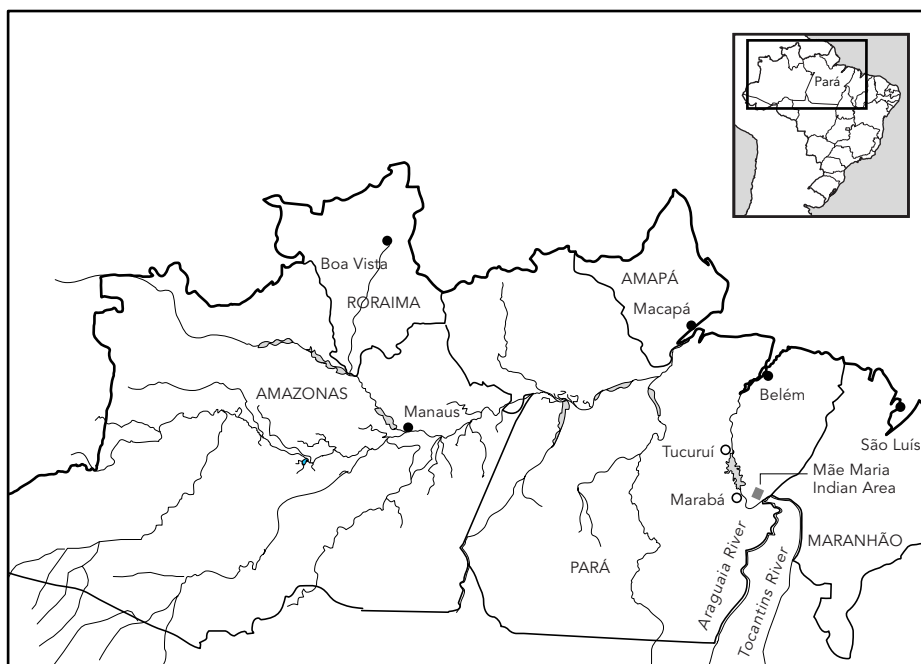
Taking into account that cervical cancer is the most common form of cancer among women in the poorest areas of the Brazil, including the Amazon Region, we mainly focused on the occurrence of the other two rarer cancer cases observed among young adults. First, a statistical evaluation on the probability of occurrence of both cancer cases by chance was ascertained (Poisson distribution) and by comparing the cancer incidence rates among Parkatêjê 20-29-year-old and those in the general population in the same age group.

Medical antecedents of both young cancer cases including exposure to ionizing radiation were investigated and their relatives interviewed. Exposure to natural radiation in the MMIA was estimated by previous available geological survey data.

Exposure to organochloride (DDT) and organophosphorus pesticides (OPH) was evaluated, respectively, by p,p'-DDT and butyryl-

Figure 1

Geographical location, Mãe Maria Indian Area, Bom Jesus do Tocantins, Pará, Brazil.



cholinesterase plasma levels ascertained from 89 individual blood samples. Plasma was separated by centrifugation of blood samples, and chromatographic analysis carried out to ascertain p,p'-DDT levels. Butyrylcholinesterase analysis was carried out according to Ellman et al. (1961).

Metal contamination was estimated by trace-element levels ascertained from 14 hair samples by mass spectrometry, which enables one to precisely ascertain the content in hair of more than 70 elements in concentration levels ranging below ppb (Harrison et al., 1969; Nojiri et al., 1989).

EMF exposure was ascertained during current community activities carried out in the village and in several sites located at a close distance or just below the overhead transmission lines (ritual races, farming, fishing, cattle herding, and praying at the cemetery). Spot and 24-hour magnetic field direct measurements (obtained with an AMEX meter; Electric Power Research Institute, 1990) were conducted over the course of six days at standardized times and locations at variable distances from the transmission lines. EMF spot measurements, taken at a close distance from the transmission lines, were further compared with estimated fields calculated from data for the same days provid-

ed by the utility company running the power lines (Figure 3), and their correlation coefficient was determined. Magnetic fields were ascertained after measurements taken one meter above ground in three orthogonal axes (B_x , B_y , and B_z), while the measured field B was obtained using the following equation:

$$B = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

Results

A census carried out in 1992 at the MMIA revealed that 44 adults in the 20-29-year age group were living in the community. By comparison with the observed cancer incidence rate in the same age group in Porto Alegre (168.2 per 100,000 in 1991), the Brazilian city with the highest cancer incidence rates (Koifman, 1995), the probability (Poisson distribution) of the occurrence of two cancer cases by chance in this age group among the Parkatêjê was less than 0.003 (three per thousand).

Both young cancer cases, as reported by their parents in direct interviews, grew up healthy with no antecedents of X-ray treatment. According to a previous comprehensive geological survey conducted in the Amazon Region (Carvalho, 1977), natural radioactivity

Figure 2

Mãe Maria Indian Area. Facilities and natural resources. Bom Jesus do Tocantins, Pará, Brazil.

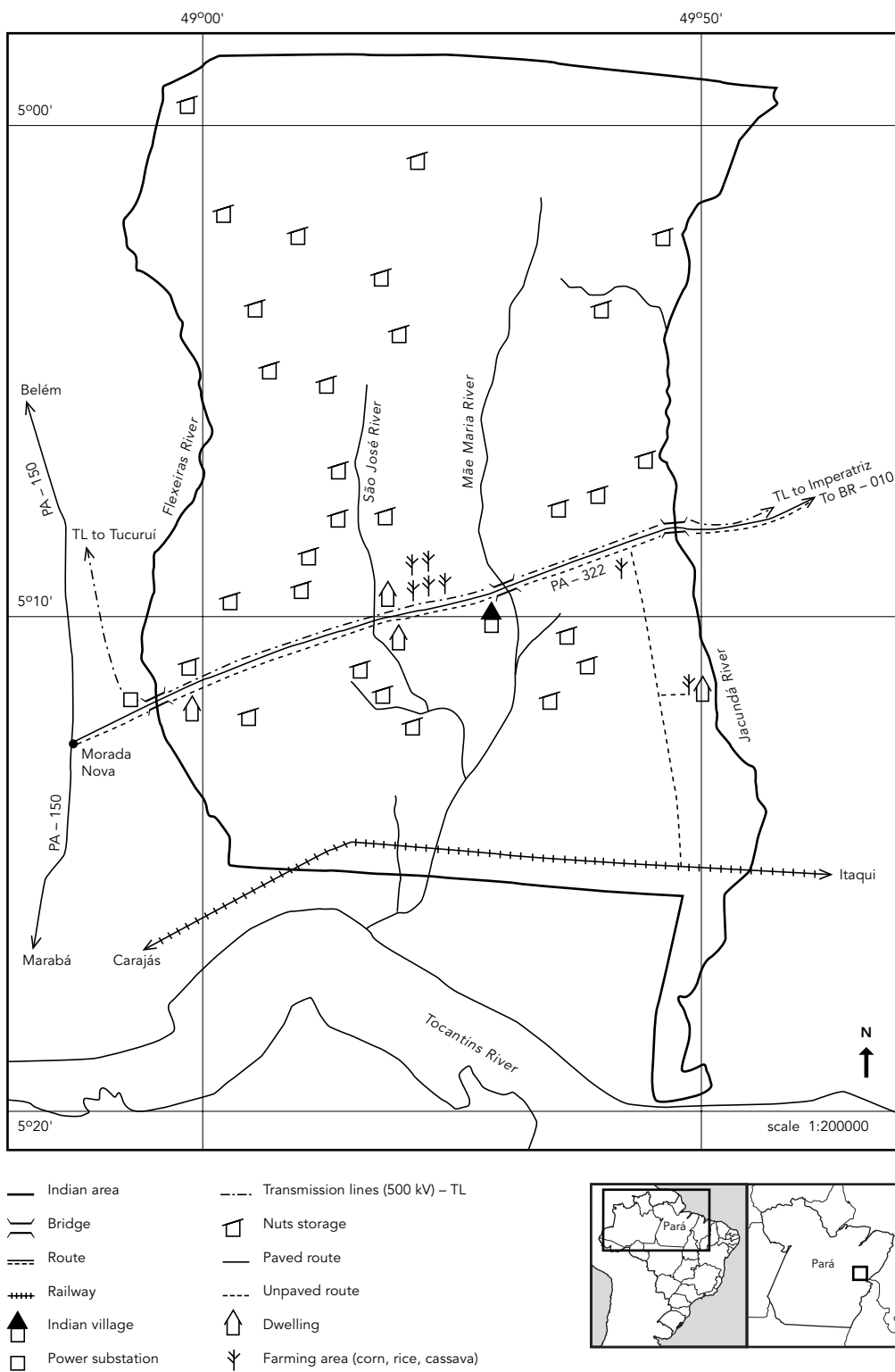
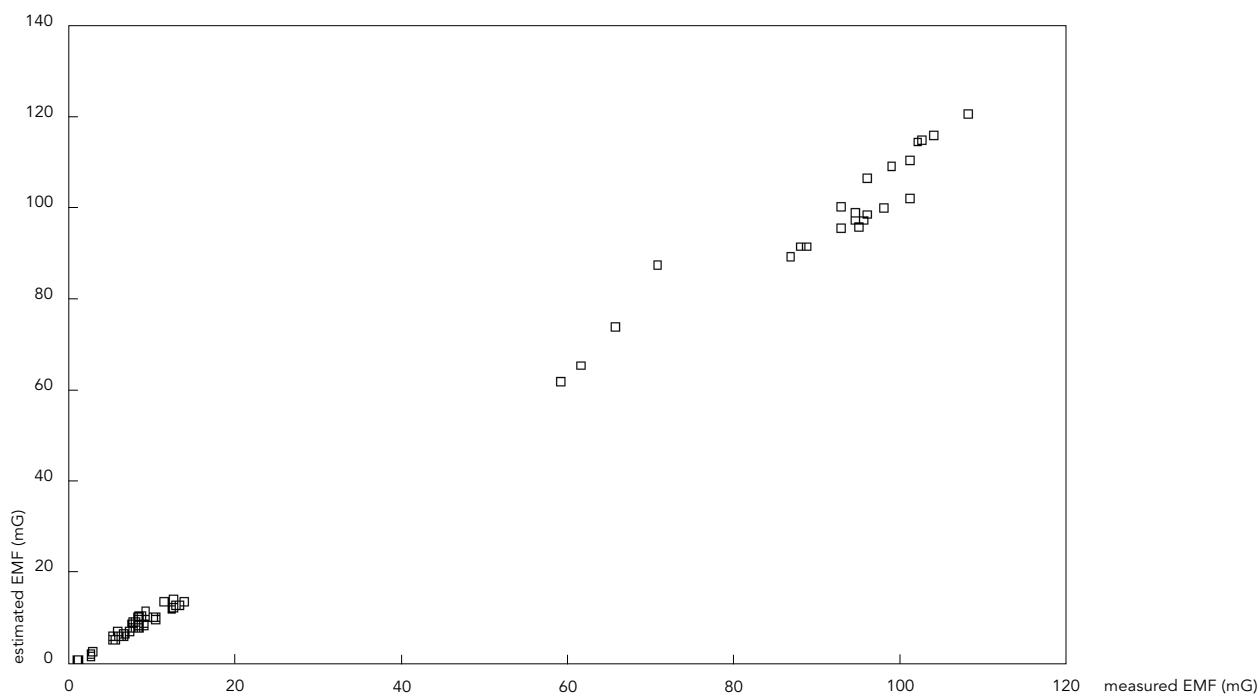


Figure 3

Measured vs estimated EMF (mG) scattergram Mãe-Maria Indian Area, october 16-21, 1994.



levels are low in Bom Jesus do Tocantins County where the MMIA Parkatêjê village is located.

Median concentration of metals in hair samples are presented at Table 1.

High levels of toxic metals such as lead (Pb), mercury (Hg), cadmium (Cd), silver (Ag), arsenic (Ar), aluminum (Al), and nickel (Ni) were not observed among the Parkatêjê. On the other hand, higher levels of barium (Ba), magnesium (Mg), manganese (Mn), and strontium (Sr) were observed when compared with general population controls.

Mean butyrylcholinesterase plasma level among the Parkatêjê was 5.0 (2.6-7.4) mM/ml, thus not suggesting recent contamination by organophosphorus pesticides (Table 2). Moreover, median levels of plasma p,p'-DDT ranged from 26.3 ppb (men 30 years of age or older) to 58.1 ppb (children), higher than reported in the literature and suggesting past exposure to DDT (Table 3). No cases of birth defects were reported in the Parkatêjê community.

In relation to EMF exposure, personal cumulative exposure to magnetic fields (Table 4) showed low levels of exposure (below 1.0 mG) in 62% of measurements, and moderate levels

(1.0-1.9 mG) were observed in 33% (7 persons, all of them young adults). Magnetic-field mean exposure during ritual races (20-30 minutes) carried out crossing the transmission lines right-of-way daily was 3.5 mG, and 6.8 mG as observed with cattle herders working under the lines. Right-of-way measurements taken at places where children routinely play and fish over a bridge on Route PA 322 ranged from 8.7 to 12.8 mG. Transmission lines were built crossing over a preexisting indigenous cemetery where ritual prayers are often performed, and mean exposure to magnetic fields in the cemetery was 95.0 mG.

Another set of magnetic field measurements, obtained at standardized times and locations at different distances from the transmission lines, was compared with data provided by the utility company running the transmission lines (Table 5). These comparisons yielded a correlation coefficient of 1.0 (1.0-1.0) based on 78 different measurements (Figure 3).

Table 1

Median metal concentrations (mineralogram) determined from hair samples, Parkatêjê Indians (Bom Jesus do Tocantins) and urban controls (Rio de Janeiro), Brazil, 1994.

Metal	Parkatêjê (mg/g)	Controls (mg/g)
Pb	3.93	< 10.0
Hg	1.83	< 2.0
Cd	0.05	< 0.5
Ag	0.05	0.9
Ba	37.98	< 3.7
As	0.04	0.4
Al	13.34	< 18.0
Ni	0.49	1.1
Bi	0.05	-
Na	118.8	-
K	16.7	-
P	551.9	156.0 - 258.0
B	0.5	-
Ca	1,187.0	151.0 - 655.0
Mg	192.4	12.0 - 34.0
V	0.08	< 0.012
Cr	0.72	0.2 - 0.4
Fe	28.43	8.0 - 24.0
Mn	2.0	0.1 - 1.1
Cu	11.09	11.0 - 33.0
Zn	149.0	145.0 - 223.0
Mo	0.06	0.03 - 0.07
Sr	14.34	0.6 - 3.8
Se	2.33	0.5 - 2.3
Au	0.012	0.1 - 0.3
Ge	0.063	0.03 - 0.09
Co	0.40	0.03 - 0.08

Table 2

Plasma butyrylcholinesterase levels (IU/ml) in Parkatêjê Indians, Bom Jesus do Tocantins, Rio de Janeiro, and Magé, Brazil, 1994.

Population	n	Mean	95% C.I.
Parkatêjê, PA	89	5.0	2.6 - 7.4
Rio de Janeiro, RJ	36	3.5	1.3 - 5.7
Magé, RJ	21	4.0	2.2 - 5.8

Discussion

The occurrence of two cancer cases among young adults in a small indian community during the same year is quite unexpected, considering the low incidence of the disease in these groups. Even taking into account eventual underreporting, these cases would be unexpected considering the small number (44 persons) in the age group from which the two cases arose.

If 20-29-year-old Parkatêjê adults had the same cancer incidence as observed in Porto Alegre, the Brazilian city showing the highest cancer incidence, 0.07 cases would be expected in this age group, and the ratio between observed and expected cases would be 28. From another perspective, 1,190 Indians 20-29 years old would be necessary to expect 2 cases of cancer if the Parkatêjê had experienced the same cancer incidence observed in Porto Alegre. If comparisons were carried out with Belém, capital of the same State of Pará where Bom Jesus do Tocantins is located, and showing an all-cancer incidence rate of 114.0/100.000 among 20-29-year-olds in 1987, 1,754 Indians would be necessary to expect 2 cancer cases, rather than the 44 in this age group then living in the MMIA village. Moreover, when comparing mortality data with the neighboring city of Marabá, 43 kilometers from the MMIA (with 21,200 inhabitants 20-29 years old according to IBGE, 1994), the same number of 2 cancer cases was reported in 1987-89 for this entire population age group (MS, 1987, 1988, 1989).

As a whole, these rough estimates suggest that the probability of the occurrence of this cancer cluster by chance is quite remote. Therefore, despite the small absolute number of cases diagnosed with cancer, the possible reasons for their occurrence should be explored.

From an epidemiological point of view, case studies suffer severe constraints in the sense that they usually do not provide enough information to allow further conclusions on cause-effect relationships. Nevertheless, they may be useful as hypothesis-generating studies, to be further evaluated through observational analytical investigations. We thus attempted to explore different exposures which could theoretically be associated with the unusual occurrence of these cases of cancer among young adult Indians.

Several conditions have been mentioned in the literature as risk factors for cancer during early adulthood, such as virus infection, exposure to ionizing radiation, natural radioactivity (radon), heavy metals, and chemical agents

such as benzene, herbicides, and pesticides. Since the first report on the association between EMF exposure and cancer (Wertheimer & Leeper, 1979), a large number of investigations on this subject has also been published, despite the controversy which still remains on this matter (Savitz et al., 1993; Savitz & Ahlbom, 1994; Carpenter, 1994; Linet et al., 1997). The occurrence of a cancer cluster among young adults living near power transmission lines which began operating ten years before the diagnoses, providing a source of various opportunities to EMF daily exposure at different intensity levels, calls attention the setting in which those cases arose.

Despite the fact that the MMIA is settled in a region surrounded by cattle farms, it still maintains large areas of original jungle in which the Parkatêjê gather nuts during the rainy season and go on monthly hunting journeys. Moreover, community races, a highly important ritual in the Parkatêjê culture, are held daily at dawn by nearly all the villagers, who either cross under the power lines going deep inside the jungle or simply wait below them for the two teams coming back, carrying ceremonial logs on their shoulders. Therefore, besides daily EMF exposure, there are abundant opportunities for virus exposure for all community members.

DDT was used in Brazil until 1994 to control malaria transmission, mainly in the Amazon Region where more than 99% of cases were diagnosed. Around 3,000 tons of this chemical were estimated to have been introduced into this region from 1988 to 1994 (Loyola, personal communication). DDT is a persistent organic environmental pollutant that is either banned or severely restricted in several countries. Nevertheless, it has been used in many areas where malaria mosquito vectors have not yet developed resistance to it.

Even considering restraints on DDT use, its presence is ubiquitous in the environment as a result of chemical and physical properties, intensive application, and persistence, remaining in the soil for many years. DDT has been shown to cause several disorders in wildlife (birds, fish, and others), besides displaying several adverse human health outcomes like carcinogenic and reproductive effects (Wolf et al., 1991, 1993; Woodruff et al., 1994; Ritter et al., 1995).

Since it has been used recently on a large scale in Brazil, DDT and metabolite serum levels can be used to estimate past exposure in the population (Anderson, 1985). An average p,p'-DDT serum level of 0.17 µg/l, standard deviation

Table 3

Plasma p,p'-DDT levels (ppb) in Parkatêjê Indians, Bom Jesus do Tocantins, Brazil, 1994.

Age	n	P ₂₅	Median	P ₇₅	Highest observation
<15 years (both genders)	13	34.2	58.1	80.0	86.6
15-29 years					
Men	26	21.6	30.8	58.0	173.4
Women	14	17.5	34.1	137.3	545.5
>29 years					
Men	22	19.6	26.3	50.9	143.3
Women	14	28.5	55.6	83.2	1160.1

P₂₅ = first quartile
P₇₅ = third quartile

Table 4

Cumulative and mean exposure to magnetic fields during selected routine activities, Parkatêjê Indians, Bom Jesus do Tocantins, Brazil, 1994.

Activity	Starting (time)	Ending (time)	Cumulative exposure (mG/h)	Mean exposure (mG)
housekeeping	6:00	9:25	2.3	0.7
ritual race	6:55	7:30	2.0	3.5
overnight and ritual race	22:00	5:50	7.8	1.0
cattle herding	9:30	13:05	24.3	6.8
below TL				
(I)	15:45	16:25	13.4	19.9
(II)	15:00	15:50	18.1	21.8

TL = transmission lines.
I and II = measurement carried out in different days.

(s.d.) 6.04, was reported for the unexposed population in Brazil (Carvalho et al., 1989). On the other hand, chlorinated pesticide serum levels ranging from 6.49 to 254.0 µg/l were observed among 51 workers spraying DDT and hexachlorocyclohexane in cocoa farming in Brazil (Carvalho et al., 1989). Serum levels higher than 30 µg/l were also found among workers spraying DDT in the Brazilian malaria control program, 9% of them with levels even higher than 50 µg/l (Franklin & Peixoto, 1988). DDT residues were also found among exposed and unexposed women in Ribeirão Preto, SP, Brazil (Matuo et al., 1992).

Bouwman et al. (1991) reported total DDT levels (p,p'-DDT + p,p'-DDE + p,p'-DDD) reaching 140.9 ppb (equivalent to µg/l), s.d. 108.3, among serum samples taken from population groups in the Kwazulu region, Africa, where

Table 5

Magnetic field spot measurements taken at different distances from 500 kV power transmission lines, Mãe-Maria Indian Area, Bom Jesus do Tocantins, PA, Brazil, October 16-21, 1994.

Site	Oct 16, 1994		Oct 17, 1994		Oct 18, 1994		Oct 18, 1994		Oct 19, 1994		Oct 20, 1994		Oct 21, 1994	
	Meas	Est	Meas	Est	Meas	Est	Meas	Est	Meas	Est	Meas	Est	Meas	Est
A	-	-	-	-	2.8	3.2	2.7	2.8	2.6	2.4	1.2	1.3	1.0	1.4
B	5.5	8.2	8.2	8.1	8.8	8.7	8.4	8.4	9.0	9.0	9.0	9.0	-	9.7
C	-	8.2	13.1	13.0	12.5	12.9	12.2	12.1	12.5	12.7	2.7	13.0	13.8	14.1
D	61.0	65.3	93.5	96.7	95.0	97.8	87.8	91.0	87.0	90.8	94.0	95.4	100.0	101.4
E	65.0	73.4	103.0	115.0	101.5	114.3	95.0	105.8	100.0	110.0	101.0	113.7	107.0	119.7
F	58.5	61.9	94.5	96.9	93.5	98.4	86.0	88.9	92.0	94.9	92.0	95.1	97.0	99.1
G	5.2	5.6	8.0	8.4	7.9	8.3	7.7	8.1	7.9	8.3	8.1	8.4	8.8	9.3
H	5.2	6.5	7.9	9.5	7.7	9.3	7.5	9.3	7.5	9.4	7.9	9.7	8.2	10.2
I	5.7	7.3	8.5	10.8	8.3	10.6	8.1	10.4	8.2	10.5	8.6	11.0	9.2	11.9
J	6.0	6.4	6.7	6.9	6.4	6.7	6.2	6.5	6.3	6.5	6.6	7.0	7.2	7.4

A = reference site located 33.5 m from the outer edge of Route PA - 322; B = outer edge of Route PA-322; C = inner edge of Route PA-322 located (45.5 m from A); D = transmission line right-of-way (80.5m from A); E = below transmission line (91 m from A); F = transmission line right-of-way (102 m from A); G = site located 132 m from A; H = site located 137 m from A; I = site located 143 m from A; J = site located 177 m from A. Meas = measured fields; Est = estimated fields.

DDT was applied in households to control malaria transmission. In this study, mean p,p'-DDT serum levels of 37.3 ppb (s.d. 27.2) were observed among exposed groups.

Pesticide exposure was a constant in the MMIA during previous decades, when DDT was periodically sprayed on the palm roofs of Indian dwellings as a regular activity of the national malaria control program. Moreover, according to this indian community's cultural habits, personal goods such as forks, combs, toothbrushes, etc., are stored on the palm roofs. When the transmission lines were built in the early 1980s, the traditional indian dwellings were replaced by brick houses, and DDT spraying was replaced by that of other insecticides; nevertheless, high serum DDT levels are still observed among the Parkatêjê Indians (Table 3). These levels among the Parkatêjê (a mean of 51.61 ppb in women, s.d. 39.62; 50.53 ppb among men, s.d. 46.79) are comparable to those observed in workers with occupational exposure to DDT in Brazil or the general population exposed in the Kwazulu Region of Africa, and several times higher than seen among unexposed population groups in Brazil.

To evaluate recent exposure to organophosphorus pesticides (OPH) (a major concern considering the proximity between the MMIA and surrounding farms), butyrylcholinesterase (BTC) was measured from blood samples drawn from Parkatêjê community members, since its enzymatic activity has been considered the most appropriate biological indicator of OPH exposure. BTC levels were higher than

observed in samples from the general population (non-statistically significant differences, Table 2), thus suggesting a low current exposure to OPH among the Parkatêjê. Nevertheless, quite high levels of exposure to OPH (plasma BTC below 3.0 IU/ml) were indeed seen in 8% of the samples (11% showed levels below 3.5 IU/ml).

Distribution of metal in hair samples was measured to evaluate possible exposure to confirmed/suspected carcinogens, such as Pb, Cr, Al, and Ni. Although only a few samples could be obtained, no elevated traces of these elements were observed. However, higher levels of Ba and Mg than usually observed in urban Brazilian populations were observed systematically in the Parkatêjê, probably resulting from the Ba- and Mg-rich indigenous diet (nuts and nut "milk") (Tsalev & Zaprianov, 1984).

Exposure to ionizing radiation has been reported in the literature as an important risk factor for several forms of cancer, including hematological diseases and sarcomas (Miller, 1989). The two young Indians who developed cancer appear to have grown up healthy, never having been submitted to X-ray treatments like those recommended decades ago for acne or *tinea capitis*. Nevertheless, screening for tuberculosis by fluoroscopy was in fact carried out sporadically in the MMIA.

Exposure to natural radioactivity (radon) has been mentioned in the literature as associated with cancer, mainly lung cancer. Nevertheless, natural radioactivity levels in the entire county where the MMIA is located are consid-

ered very low. The region as a whole is not located in an anomalous geological area, showing non-radioactive rocks originating in the Maranhão Basin, as reported in a comprehensive geological survey conducted earlier in the Amazon Region by the Companhia de Pesquisa de Recursos Minerais in 1977 (Carvalho, 1977).

Since the first report on the association between EMF exposure and cancer during childhood (Wertheimer & Leeper, 1979), an impressive number of reports on that association has been published, also including workers undergoing occupational exposure (Thériault et al., 1994; Savitz and Loomis, 1995) and the general population (London et al., 1991; Feychting & Ahlbom, 1993; Washburn et al., 1994; Savitz & Ahlbom, 1994). Despite severe criticism due to methodological flaws in several epidemiological studies exploring the association (Savitz & Ahlbom, 1994), it has not been possible to dismiss the evidence after two decades of intensive research. After all, despite the fact that the incidence of selected cancer sites (mainly leukemia, brain cancer, non-Hodgkin lymphoma, soft-tissue sarcoma, and lung cancer) has been linked to EMF exposure from different sources such as power transmission lines, the causal nature of that association remains controversial, and the debate continues to be raised (Youngson et al., 1991; Kavet et al., 1992; Tenforde, 1992; Verkasalo, 1993; Feychting & Ahlbom, 1993; Linet et al., 1997).

In 1982, two 500 kV transmission lines were built crossing the MMIA along an unpaved road previously built in this area (Route BR-PA 322). Traffic used to be, and still is, very scarce along this route, hence exposure levels to polyamino-hydrocarbons and other chemicals from motor-vehicle exhaust are very low. Despite the fact that the Parkatêjê village is located 700 meters from the transmission lines, many opportunities for close contact by the villagers have been observed: the lines were built directly over the Parkatêjê cemetery, where praying is often performed; their cattle graze below them; community ritual races are held daily at dawn by virtually all the villagers, who cross under the lines into the jungle and come back carrying heavy logs to the village; community crops (corn, cassava, beans, pumpkin, etc.) are grown along the power line right-of-way; children play and fish from a road bridge located just a few meters away; groups of 20-30 Indian villagers travel daily for an hour along the transmission lines in a community-owned truck to trade in the city of Marabá, 43 kilometers away; and hunting areas and nut groves are also reached by crossing under the lines.

Thus far, an approach to all these possible risk factors for the observed cancer cluster led us to not consider metal contamination, ionizing radiation, or exposure to natural radioactivity very relevant as possible explanations. On the other hand, past exposure to DDT, viruses, and EMF were not to be excluded.

According to the well-demonstrated and scientifically-acknowledged multiple-step model of carcinogenesis, cancer arises following multiple changes in a single normal cell, which experiences irreversible alterations in DNA (cell induction or initiation). The altered cell may remain in this condition for life with no major repercussions. Nevertheless, if other agents continuously stimulate cell division, the altered cell can reproduce, yielding a clone displaying the same genetic modifications (promotion). Although reversible, if stimulation persists, the mass of altered cells grows, leading to an autonomous process to the point where clinical manifestations begin (tumor progression). Different genetic changes participate in the whole process, mainly those involved with cell division enhancement (oncogenes) or inhibition (antioncogenes or tumor-suppressor genes) (Moolgavkar, 1986; Bishop, 1987; Brandt-Rauf & Pincus, 1987; Hermo, 1987; Weiss, 1990).

According to present knowledge, only a few carcinogenic agents (like ionizing radiation and smoking) are able to lead to the entire process alone and are thus called complete carcinogens. In general, biological studies on cancer development show that several agents take part in different steps, making the overall process the result of several changes produced by different interacting risk factors, leading together to a specific neoplasm.

In the case of the cluster analyzed here, exposure to virus or pesticides, mainly DDT, could theoretically be involved with cancer development alone, i.e., acting as complete carcinogens.

Another possible explanation is that one or both of the above acted as tumor initiators, altering cell DNA and starting a process followed by a promoter stimulation. Among the exposures analyzed in this case study, continuous EMF exposure from the transmission lines at the Parkatêjê settlement could be a candidate. Non-ionizing radiation may have played a role as a cancer promoter, thus stimulating reproduction of a preexisting altered cell, as previously raised as a hypothesis for EMF exposure and cancer (Easterly, 1981; Koifman, 1993).

The anatomical sites in which cancer cases were observed among young Parkatêjê, a

leukemia and a soft-tissue sarcoma, are both included among those reported in the literature as associated with this type of exposure. Moreover, timing between the start of this exposure (1982) and cancer diagnosis (1992) may be considered consistent in terms of biological plausibility (latency period) expected to be shown for a promoter. In this sense, promoters usually participate in the latter periods of tumor development, closer to clinical onset of disease.

The biological plausibility of EMF involvement in carcinogenesis has also been suggested by other cell mechanisms, such as the subsequent low melatonin levels observed among animals continuously exposed to EMF (Tamarkin et al., 1982; Shah et al., 1984; Stevens, 1994) and the *in vitro* changes in tumor biomarker levels (adenosine deaminase and ornithyl-decarboxylase) in cells also exposed continuously to EMF (Parola and Markel, 1994).

EMF exposure has been studied in several epidemiological surveys in which other environmental risk factors were controlled as possible confounders. As previously mentioned, a case study like ours is not able to test a hypothesis of causal association, but does raise hypotheses for further evaluation. In this sense, the observed cluster of cancer among young

Indians as reported here perhaps indicates a joint action of EMF continuous exposure over time subsequent to DNA change caused by tumor initiators. In this case, the combined action of the two factors could have started the several steps of biological changes leading to the unusual cancer cluster in the Indian community. We believe that further studies should focus on the interaction in such joint relationships, little analyzed in combination by previous epidemiological investigation.

Conclusions

A cancer cluster among young adults was observed in a small Indian community in Brazil. The probability that this event occurred by chance was considered remote by the authors. No evidence was observed of metal contamination by Pb, Al, Cd, or Ni or prior exposure to natural radioactivity or ionizing radiation. Evidence of past exposure to DDT and recent minor exposure to organophosphorus pesticides was suggested. Several opportunities for exposure to very low electromagnetic fields originating from electric power transmission lines were also observed during daily activities in this community.

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