

# Occupational and residential exposure to electromagnetic fields and risk of brain tumors in adults: a case-control study in Gironde, France

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The etiology of brain tumors remains largely unknown. Among potential risk factors, exposure to electromagnetic fields is suspected. We analyzed the relationship between residential and occupational exposure to electromagnetic field and brain tumors in adults. A case-control study was carried out in southwestern France between May 1999 and April 2001. A total of 221 central nervous system tumors (105 gliomas, 67 meningiomas, 33 neurinomas and 16 others) and 442 individually age- and sex-matched controls selected from general population were included. Electromagnetic field exposure [extremely low frequency (ELF) and radiofrequency separately] was assessed in occupational settings through expert judgement based on complete job calendar, and at home by assessing the distance to power lines with the help of a geographical information system. Confounders such as education, use of home pesticide, residency in a rural area and occupational exposure to chemicals were taken into account. Separate analyses were performed for gliomas, meningiomas and acoustic neurinomas. A nonsignificant increase in risk was found for occupational exposure to electromagnetic fields [odds ratio (OR = 1.52, 0.92–2.51)]. This increase became significant for meningiomas, especially when considering ELF separately [OR = 3.02; 95 percent confidence interval (95% CI) = 1.10–8.25]. The risk of meningioma was also higher in subjects living in the vicinity of power lines (<100 m), even if not significant (OR = 2.99, 95% CI 0.86–10.40). These data suggest that occupational or residential exposure to ELF may play a role in the occurrence of meningioma.

In the past decades the incidence of primary brain tumors has been increased in many countries, a trend probably partly explained by the development of imaging techniques (X-ray computed-assisted tomography, magnetic resonance imaging).<sup>1–4</sup> However, spatial and temporal changes in the incidence of brain tumors also suggest the role of environmental factors. Among them, both high- and low-dose ioniz-

ing radiation have been proven to play a role in brain tumors, but they explain only a small proportion.<sup>5</sup> Other hypothetical environmental causes such as pesticides, solvents, metals, nitroso compounds have been suggested by occupational epidemiological studies.<sup>6</sup>

The universal use of electricity and the rapid development of associated technologies in the past decades raise the hypothesis of the potential contribution of electromagnetic fields (EMFs) in the development of some cancers, including brain tumors. The recent rapid increase in the use of cellular phones in the 1990s has stimulated epidemiological research on the contribution of radiofrequencies (RFs) to the development of brain tumors. Several meta-analyses on the effects of RF have been performed, the most recent ones focusing on studies with long-term cell phone use (>10 years).<sup>7,8</sup> Two streams of data have been identified: the “Hardell group” studies and the “INTERPHONE group” studies. While the first have concluded in elevated risks of developing ipsilateral astrocytoma and acoustic neurinoma,<sup>9</sup> the data from the second international group do not globally support the same conclusion.<sup>10</sup> Extremely low frequency (ELF) fields (power

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lines, electrical appliances, *etc.*) were considered separately from RFs as any effects they may produce on cells could be due to various mechanisms.<sup>11</sup>

ELFs have been classified as possibly carcinogenic to humans by the International Agency for Research on Cancer because of epidemiological evidence for childhood leukemia, but the evidence concerning brain cancer risk is only inadequate.<sup>12</sup> A recent review confirmed that the available data remain inconclusive concerning the role of RF in brain tumors, and that more studies are needed for slow-growing tumors such as meningiomas as well as for gliomas among long-term users.<sup>7</sup> As the effects of EMFs remain controversial and because the etiology of brain tumors is largely unknown, there is a need for more data from independent studies.

Our study investigated the putative association between residential and occupational EMFs and the risk of brain tumors in a French population-based case-control study.

## Material and Methods

### Study subjects

A population-based case-control study (CEREPHY) on central nervous system (CNS) tumors was carried out in the French administrative area of Gironde in southwestern France (1,437,863 inhabitants in 2007) to study occupational and environmental risk factors. We briefly summarize here the methods described in a previous paper.<sup>13</sup>

Eligible cases were all subjects aged 16 years and over, newly diagnosed with a brain tumor during the period from May 1, 1999 to April 30, 2001 and living in Gironde when diagnosed. Topography codes for primary brain tumors following the International Classification of Diseases for Oncology third edition (ICD-O-3) were included in the study: C70.0–C70.9 (meninges), C71.0–C71.9 (brain) and C72.2–C72.9 (cranial nerves and other parts of the CNS). In addition, cases were grouped according to ICD-O-3 morphology codes as gliomas (codes 9382–9451), malignant and benign meningiomas (codes 9530–9538), acoustic neurinomas (code 9560), lymphomas (code 9590) and other unspecified primary brain tumors. The tumor grade was classified according to the World Health Organization classification. Patients with neurofibromatosis, Von-Hippel Lindau diseases or AIDS were excluded. Other exclusion criteria were metastasis, recurrent tumors, or main residence outside the study area. All diagnoses were confirmed using two methods: (i) whenever histological diagnosis was available, the slides were systematically re-examined by a pathologist not involved in the initial diagnosis, (ii) for cases with no histological diagnosis, an assessment based on clinical and radiological criteria was carried out by a neurosurgeon and a neuroradiologist. Among the 315 eligible cases, 221 (70%) were included in the study. The main reasons for nonparticipation were death (37%), refusal (15%), incapacity because of disease (48%).

Controls were randomly selected from the local electoral rolls, which automatically registered all French subjects aged 18 years and over since 1997. This list contains name,

addresses, dates of birth, gender and place of residence. For each eligible case, two controls were individually matched on age (more or less 2 years), sex and department of residence. Among the 642 eligible and reachable controls, 442 controls participated (69%). Two hundreds refused for health (24%) or other reasons (76%).

### Data collection

All cases and controls received general information on the study and thereafter were phoned to ask for their participation. Trained interviewers administered a face-to-face standardized questionnaire including detailed information about demographic data (age, sex, educational level and marital status), lifestyle (tobacco and alcohol consumption), medical history (other cancerous pathology, head trauma), environmental risk factors (EMFs, pesticides and chemical agents) including information on mobile phone use. Furthermore, lifetime residential histories (for all places where the individual lived for more than 1 year) and occupational history were obtained for all subjects. For each job held for 6 months or more, job title, the type of industry, dates of beginning and end and detailed tasks performed were collected.

### Occupational exposure assessment

Two industrial hygienists blind to case-control status expertised the job histories to determine exposure parameters. Thus, for each job of a given individual, exposure assessment included determination of (i) the type of EMF (ELF, RF), (ii) the exposure duration (*D*) and (iii) the exposure probability (*P*). Probability was classified into four categories from nonexposed (0), possibly exposed (1), probably exposed (2) and certainly exposed (3). Duration corresponded to the number of years EMF exposure was considered present in a specific job. In a second step, expert judgement, based on the individual information, was compared to data from a Swedish Job Exposure Matrix.<sup>14</sup> When differences could be explained by variations in jobs between Sweden and France, it was the judgment of our experts which prevailed. For example, while postmen were considered exposed to EMF according to workday mean values in the Job Exposure Matrix, they were not systematically classified as exposed in our study. Indeed in France, some postmen do not sort the mail but only deliver it and thus were not considered exposed to the EMF of the sorting machines.

A cumulative lifetime score (*S*) for each type of EMF (RF, ELF) was calculated for each subject as follows:  $\sum_{i=1}^n$  probability (*P*)<sub>*i*</sub> × duration (*D*)<sub>*i*</sub>, where *i* indicates a given job in the calendar. In the analysis, occupational exposure was primarily considered as a dichotomous variable (*i.e.*, exposed vs. never exposed) and then according to the quartiles of cumulative exposure calculated on the whole population.

### Residential exposure assessment

Residential exposure to EMFs was assessed by calculating the distance between high power lines and place of residence at

the time of diagnosis for cases and at the time of interview for controls. High (90 kV and 63 kV) and very high (400 kV and 225 kV) power lines were taken into account whether they were overhead or underground. Four steps were completed for geocoding places of residence, blinded to the status disease and without knowledge of the position of the power lines: (i) all addresses collected on the questionnaire at interview time were checked and corrected if necessary and possible. If addresses remained incomplete, they were considered as missing, (ii) these addresses were located on the National Geographic Institute maps (scale 1:25.000°), on city maps (scale 1:5.000°) and on cadastral maps. Additionally, we used a website with aerial photography to help the localization. When all these attempts failed, we went on site to better locate the home, (iii) addresses were geocoded using a Geographical Information System (GIS)—Geoconcept, (iv) consistency of positioning from GIS with location on the maps was checked. A 100-m distance on both sides of the power lines was retained as the threshold for environmental exposure. This distance was consistent with data published previously and relevant according to the attenuation of EMFs with distance.<sup>11</sup> For each subject living within a corridor of 100 m from a power line, the shortest perpendicular distance to the power line was calculated.

As subjects were questioned on their residence near a high-power line, a positive answer to this question was considered. This could reflect high exposure to ELF in previous homes. Use of cell phones and the practice of an amateur radio operation were also collected and were used as dichotomous variables in our analysis.

### Potential confounders

Exposure to pesticides and smoking were described in the literature as potential confounders and were taken into account.<sup>15,16</sup> Occupational exposure to some chemicals (pesticides, petroleum, solvents, lead and nitrosamines) was assessed by industrial hygienists through job history and treated as a dichotomous variable (exposed/not exposed). If the individuals were exposed to at least one or more types of chemical exposure, they were considered exposed “to at least one occupational exposure to chemicals.” Tobacco consumption was also taken into account as a dichotomous variable (past or present smoker/nonsmoker).

Moreover, three variables were retained to assess environmental exposure to pesticides: residency in a rural area, living in a vineyard area and a generic question on treatment of home plants. Educational level was used as a proxy for socioeconomic status and classified into four categories (no or primary school/middle school/high school/university).

### Statistical analysis

Individual characteristics and EMF exposures were described and compared between cases and controls using the usual tests (Chi-square, Student's test). We performed univariate analysis to search for an association between potential risk

**Table 1.** Distribution of cases according to histological type by sex, CEREPHY study, Gironde, France, 1999–2001

Histological type	Males (n = 95)		Females (n = 126)	
	N	%	n	%
Glioma	60	63.2	45	35.7
Astrocytoma grade 1	4	6.7	2	4.5
Astrocytoma grade 2	5	8.3	5	11.1
Astrocytoma grade 3	5	8.3	3	6.7
Glioblastoma	43	71.7	29	64.4
Other	3	5.0	6	13.3
Meningioma	7	7.4	60	47.6
Neurinoma	18	18.9	15	11.9
Lymphoma	4	4.2	3	2.4
Other types <sup>1</sup>	6	6.3	3	2.4

<sup>1</sup>Haemangioblastoma (n = 7), medulloblastoma (n = 1) and choroid plexus papilloma (n = 1).

factors and tumors. Variables associated both with brain tumors and exposure in univariate analysis ( $p < 0.25$ ) were retained in multivariate models. Conditional logistic regression analysis for matched studies was performed with the SAS statistical program (SAS PHREG procedure). Odds ratios (OR) and 95 percent confidence intervals (95% CI) were obtained.

Dose-response patterns were estimated for quartiles of occupational exposures to EMFs. People exposed at background levels to EMFs were considered as the reference category.

Separate analyses were carried out for gliomas, meningiomas and acoustic neurinomas because etiology may differ by tumor type.

## Results

### Population

The study included 221 cases with the following histological types: gliomas ( $N = 105$ ), meningiomas ( $N = 67$ ), acoustic neurinomas ( $N = 33$ ), brain lymphomas ( $N = 7$ ) and others ( $N = 9$ ) and 442 controls (Table 1). Eighty-seven percent of the cases were histologically confirmed and others were ascertained by a clinical expertise. Table 2 presents the demographic characteristics of cases and controls. Participating cases were significantly younger and less frequently presented with gliomas and lymphomas but did not differ for rural/urban residence. Participating controls did not differ significantly from participating controls in age, sex or in rural/urban setting.

### Occupational exposure to EMF

Expertise of job histories resulted in 115 subjects (17.3%) occupationally exposed to EMF during their lifetime, 101 (15.2%) exposed to ELF and 35 (5.4%) exposed to RF. Cases

**Table 2.** Demographic and confounding characteristics of brain tumor patients and controls in a population-based case-control study, Gironde, France, 1999–2001

	Cases (n = 221)		Controls (n = 442)	
	Number	%	Number	%
<b>Sex (N = 663)</b>				
Females	126	57.0	252	57.0
Males	95	43.0	190	43.0
<b>Marital status (N = 662)</b>				
Married/cohabitant	159	71.9	330	74.7
Widow	27	12.2	50	11.3
Single/divorced	34	15.4	62	14.0
<b>Education level* (N = 662)</b>				
No or primary school	74	33.5	122	27.6
Middle school	82	37.1	141	31.9
High school	33	14.9	104	23.5
University	32	14.5	74	16.7
<b>Residency in rural area (N = 663)*</b>				
No	78	35.3	125	28.3
Yes	143	64.7	317	71.7
<b>Smoking (N = 663)</b>				
No	125	56.6	249	56.3
Yes	96	43.4	193	43.7
<b>Occupational exposure to chemicals (N = 663)*</b>				
No	155	70.1	348	78.7
Yes	66	29.9	94	21.3
<b>Treatment of home plants (N = 654)*</b>				
No	195	88.2	422	95.5
Yes	19	8.6	18	4.1

\* $p < 0.05$ .

were more frequently exposed to EMF than controls (20.4% vs. 15.8%,  $p = 0.12$ ), a difference explained by a higher proportion exposed to ELF (19.0% vs. 13.4%,  $p = 0.048$ ). A low and comparable proportion of cases (5.0%) and controls (5.7%) were exposed to RF, and most of them (61.1%) were also exposed to ELF. EMF exposure was considered possible in 66 subjects (57.4%), probable in 27 (23.5%) and certain in 22 (19.1%).

Analysis adjusted on potential confounders (educational level, residency in a rural area, treatment of home plants, occupational exposure to chemicals) is presented in Table 3 for all tumors and for histological subgroups. A nearly significant increase in risk was observed for occupational exposure to EMF (OR = 1.52; 0.92–2.51) and to ELF separately (OR = 1.59; 0.97–2.61). When considering the quartiles of cumulative exposure to ELF, no significant linear trend was observed: the higher risks were observed in the first (OR = 2.20; 0.91–5.34) and third quartiles (OR = 2.58; 1.02–6.53) while the ORs were, respectively, OR = 0.76; 0.28–2.06 and

OR = 1.33; 0.54–3.27 in the second and fourth quartiles. The increase in risk remained moderate in gliomas (OR = 1.64; 0.78–3.48), while a doubling in risk was observed for meningiomas (OR = 2.19; 0.76–6.31). This result was not significant because of the small size of our study (only 13 cases exposed). Concerning neurinomas, risk calculation was rather imprecise as based on only four exposed cases. It showed a slight decrease (OR = 0.84; 0.20–3.49).

Results by histological subtypes were more obvious when considering ELF exposure specifically. Risk for glioma was only 1.20 (0.66–2.17) while a statistically significant trebling of risk was observed for meningiomas (OR = 3.02; 1.10–8.25). In the highest quartile of cumulative exposure to ELF, a significant association was observed for meningioma (OR = 6.82; 1.01–45.96) but the trend test was not significant (result not shown).

#### Environmental exposure

One hundred and fifty-nine subjects (24%) reported that they were mobile phone users. The duration of use exceeded

Table 3. Odds ratios for brain tumors according to occupational and environmental exposure to electromagnetic fields, CEREPHY study, Gironde, France, 1999–2001

	All brain tumors (n = 221)			Gliomas (n = 105)			Meningiomas (n = 67)			Acoustic neurinomas (n = 32)		
	No. of cases <sup>1</sup>	No. of controls <sup>1</sup>	OR <sup>2</sup>	95%CI <sup>3</sup>	No. of cases <sup>1</sup>	No. of controls <sup>1</sup>	OR	95%CI	No. of cases <sup>1</sup>	No. of controls <sup>1</sup>	OR	95%CI
<b>Occupational exposure</b>												
Occupational exposure to EMF												
Unexposed	156	339	1		60	165	1		51	119	1	
Exposed	40	63	1.52 <sup>4</sup>	0.92–2.51	18	42	1.64 <sup>7</sup>	0.78–3.48	13	13	2.19	0.76–6.31
<b>Occupational exposure to ELF</b>												
Unexposed	165	352	1		84	174	1		51	120	1	
Exposed	38	52	1.59 <sup>5</sup>	0.97–2.61	21	36	1.20	0.66–2.17	13	12	3.02	1.10–8.25
<b>Occupational exposure to RF</b>												
Unexposed	148	375	1		71	191	1		61	121	1	
Exposed	7	22	1.50 <sup>6</sup>	0.48–4.70	7	16	1.44 <sup>7</sup>	0.50–4.13	0	2	–	–
<b>Environmental exposure</b>												
Proximity to power lines												
> 100 m	187	384	1		90	182	1		57	119	1	
≤100 m	16	20	1.51 <sup>5</sup>	0.74–3.07	5	12	0.66 <sup>8</sup>	0.21–2.07	7	6	2.99	0.86–10.40
<b>Mobile phone</b>												
Unexposed	172	329	1		79	152	1		53	106	1	
Exposed	47	112	0.82 <sup>5</sup>	0.53–1.26	26	58	0.85	0.49–1.49	12	27	0.88	0.38–2.04

<sup>1</sup>Totals may differ because of missing data. <sup>2</sup>OR: odds ratios. <sup>3</sup>CI: confidence interval. <sup>4</sup>Conditional logistic regression (with age, sex and place) adjusted for education and treatment of house plants.

<sup>5</sup>Conditional logistic regression (with age, sex and place) adjusted for education. <sup>6</sup>Conditional logistic regression (with age, sex and place) adjusted for education, treatment of house plants and exposed at least to one occupational exposure. <sup>7</sup>Conditional logistic regression (with age, sex and place) adjusted for antecedents of viral disease and treatment of house plants. <sup>8</sup>Conditional

logistic regression (with age, sex and place) adjusted for living in rural city.

10 years only for one subject and 5 years for 12 subjects. Thirty-six subjects (5.3%) reported having been an amateur radio-operator and 125 (19.2%) having lived near a power line during their life. None of these rough indicators of environmental exposure to EMF was found statistically associated with brain tumors (Table 3). A slight increase was observed for reporting a residency near a power line (OR = 1.24, 0.82–1.87) and for amateur radio practice (OR = 1.39, 0.67–2.86), while a nonsignificant decrease in risk was observed in mobile phone users (OR = 0.82; 0.53–1.26), which was similar in the different histologic types.

Geopositioning of the addresses at interview and calculation of the distance to power lines classified 36 subjects (5.9%) as living at less than 100 m from a power line. The lines were mainly 63 kV or 90 kV but 10 subjects lived near a 225 kV or a 400 kV line. Only a few cases lacked data because of incomplete addresses (8.3%) but this was not related to case-control status. These cases were mainly men living in rural areas.

A nonsignificant increased risk of brain tumors was observed for subjects residing less than 100 m from a power line (OR = 1.51; 0.74–3.07). Analysis by histological subgroups revealed heterogeneity: the risk tended to be lower for gliomas (OR = 0.66; 0.21–2.07) and higher for meningiomas (OR = 2.99; 0.86–10.40) and neurinomas (OR = 3.23; 0.28–36.62). Among the 13 meningioma cases classified as living near a power line, 12 lived near a 63 kV line. The average distance to these lines was 53.6 m, and the average duration of residency was 23 years.

## Discussion

Even if not statistically significant, an increase in the risk of brain tumors was observed in our study for occupational exposure to EMF, and it was more pronounced specifically with ELF. This increase was higher for meningioma with a statistically significant trebling of risk of meningioma in subjects occupationally exposed to ELF. Moreover, meningiomas were also associated with residential exposure to EMFs in subjects residing near power lines. Thus our results suggest an association between EMF exposure, in particular ELF, and meningiomas.

We did not find any significant association with RF but the frequency of occupational RF exposure and mobile phone use was quite low in our population, while associations with other brain tumor types were weaker or not found.

One strength of our study is the population-based design, with an active enrolment of incident brain tumors over 2 years in a defined geographic area, thus minimizing any selection bias, and a face-to-face interview enabling individual data to be collected. Malignant and benign tumors were identified continuously during the study period in collaboration with several departments of the teaching hospital. Data from the Diagnostic Related Group of the hospital discharge system were obtained as an additional source for identifying cases in the clinics, thus ensuring a high quality registration. It remains possible that some tumors were not collected, in particular in the elderly, for whom surgical indications are

more limited. Nevertheless, the major developments in technologies generating EMF have mostly taken place in recent decades, so the elderly have not necessarily been more exposed. We also observed a lower participation rate of subjects with aggressive forms of brain tumors such as gliomas and lymphomas. A Canadian study suggested that the risk association could be stronger for more aggressive forms, which was judged consistent with the hypothesis that magnetic fields act at the promotional stage.<sup>17</sup> If so, the risk we found in our study could be underestimated.

Lifetime occupational and residential histories collected in a face-to-face interview made it possible to assess occupational and environmental exposure to EMF. Thus, exposure assessment did not involve subjects' memory and recall bias could be expected to be lower when compared to studies where exposure assessment was based on subjects' reports. This is especially important in a study exploring brain tumors, a disease likely to impair cognitive functioning. Indeed it is less difficult for subjects to recall their occupations or residences than specific exposure. There are also limitations in the methods used for exposure assessment. Occupational EMF exposure was assessed from job histories and not from individual measurements. To minimize bias, exposure assessment was carried out thoroughly by two hygienists blind to the disease status. Even so, a classification bias cannot be completely ruled out as conditions of work may vary from one job to another and from one period to another in the same job.<sup>18</sup> Real exposure could only have been documented by field measurements in the work place, but this was not feasible for all the subjects and even less so for their whole career. However, it can be assumed that exposure based on expertise is likely to bias the results toward the null as possible classification errors would have smoothed differences of exposure between cases and controls. Thus, it is not likely to explain the positive associations we found.

In the literature, residential exposure to power lines has been investigated for distances from 50 to 500 m.<sup>11</sup> Increasing our 100-m limit around the power lines would have increased the number of exposed subjects but would have decreased the specificity of exposure assessment. Sources of home exposure to EMF other than power lines could be of interest, such as electrical appliances, electric transformers and home configuration. However, this information over a lifetime could not be collected accurately. Moreover, even though electrical appliances may produce high EMFs, they are usually intermittent, so the fields are present over short periods and decrease very quickly with distance. The use of a GIS is an asset in our study. Although a time-consuming task, precise localization of the subjects provided accurate data regarding distance to power lines. Anyway it remains unclear how well the different methods for assessing EMF exposure (spot measurements in specific rooms, prediction models from geospatial propagation models and behavioural characteristics, geocoded distances to sources, self-reported data) represent personal exposure to all relevant sources of

EMF lifelong. Personal measurements can be considered as the reference method but they are not feasible for collecting information in large epidemiological studies and on long-term exposure. The importance of home appliances as contributors to residential exposure is not clearly assessed. Some authors in United Kingdom have argued that they could be responsible for the main part of residential exposure (77% of exposure above 0.2  $\mu\text{T}$  and 57% of those above 0.4  $\mu\text{T}$ ) while high voltage sources would account for the rest.<sup>19</sup> But some others say power lines represent the major source of residential exposure.<sup>20</sup> Differences might depend on electrical system available in the various countries and the ground current they generate. Further studies on exposure levels and determinants are needed to solve controversies. Anyhow, even if the surrogate for exposure we used (distance to power lines), is likely to have reduced the power of the study and to have lowered the risks, it does not question the association we found.

Occupational exposure to chemicals may introduce confounding in studies on brain tumors and EMF as it may occur together with EMF in the same jobs and has been suspected to play a role in tumorigenesis. Yet it has rarely been taken into account in published literature, and one study even suggested an interaction between EMFs and brain tumors.<sup>21</sup> We controlled our results for this factor with a rough but available indicator for all individuals.

As the study by Wertheimer in 1979,<sup>22</sup> that found a difference in risk of childhood cancer related to the electrical configuration near the home, many studies have explored the role of EMF in tumors, with specific attention being paid to leukemia and brain cancer.<sup>23</sup> Occupational exposure, mainly ELF, deserves specific interest as it is considered greater than that in the general population and thus offers a better opportunity for detecting risks, if any. Several meta-analyses have combined results from studies on occupational ELF and brain tumors, first in large cohorts of electric utility workers<sup>24</sup> and later on populations including a wide range of exposed jobs.<sup>25–27</sup> The latest one identified 48 brain cancer studies exploring occupational exposure and calculated an overall moderate but significant risk of 1.14 (1.07–1.22).<sup>27</sup> Heterogeneity between studies led to the conclusion that exposure assessment is a major challenge, and this has stimulated significant improvements over time in the methodology and quality of research in this area. However, less attention has been paid to consistency and accuracy in health outcome. Few studies have focused separately on histological subtypes and, if they did, it is gliomas that have attracted most attention. However, our results are consistent with the findings of Rodvall<sup>28</sup> who found a nonsignificant increase in risk of meningioma in subjects occupationally exposed to ELF (OR = 1.8; 0.3–3.6) and no evidence in glioma (OR = 1.0; 0.4–2.4). Both these sets of findings underline the necessity to consider not only brain tumors globally but also histological subtypes such as meningiomas.

The role of ELF residential exposure has been mainly studied in children. A recent meta-analysis identified 13 studies exploring this hypothesis and calculated summary effect

estimates close to 1.0.<sup>29</sup> In the highest exposure category (above 0.3 or 0.4  $\mu\text{T}$ ), the estimate reached 1.68 (0.83–3.43). However, these results cannot be extrapolated to adults as histological subtypes differ substantially in age groups and, in particular, meningiomas occur only exceptionally in children. There have been very few studies in adults and most of them were carried out in the 1990s, after which scientific interest shifted toward RF because of the sharp increase in mobile phone use. All the studies on residential ELF in adults found risks close to the unity, but exposure assessment was rough, and the studies considered all types of brain tumors together.<sup>30–35</sup> A more recent study analyzed the risk of brain tumors according to histological subtypes in adults living close to high voltage lines in Norway and found an increase in risk for meningiomas (OR = 2.1; 0.8–5.5) for an exposure exceeding 0.2  $\mu\text{T}$ , while the risk was 1.3 (0.6–2.6) for gliomas.<sup>36</sup> In a study exploring the role of several electric appliances used near the head, a strong association was found between meningioma and electric shaver use (OR = 10.9; 2.3–50) although the number of exposed cases was limited ( $n = 35$ ) and no other study has been performed to date to confirm this result.<sup>37</sup>

Although based on a limited number of exposed participants, our results suggest an association between meningiomas and exposure to ELF. This result warrants attention if one considers that few studies to date have explored the association between ELF and histological subtypes of brain tumors, especially in adults, for whom RF from mobile phone use is now attracting all the attention. Meningiomas are very rare in children and are more common in women than in men.<sup>38</sup> Because studies more frequently included children (for residential exposure) and men (for occupational exposure), there is a need to undertake studies specifically focusing on meningiomas, which account for 20% of intracranial tumors in men and 38% in women, and for which etiological research remains scarce. Recommendations concerning EMF exposure assessment in epidemiological studies have now been clearly laid down<sup>39</sup> and considerable improvement has already been made in recent years from the methodological point of view. Health outcome assessment is also a crucial challenge and poor classification of brain tumors may also lead to inconclusive results or to biased assessment of risks. Additional results from a larger sample will be available in the coming years in France: the analysis of a larger case-control study, the CERENAT study, including 596 brain tumors (218 meningiomas, *i.e.*, three times the number included in our article) is ongoing.

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