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Evidences of the (400 MHz – 3 GHz) radiofrequency electromagnetic field influence on brain tumor induction

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ABSTRACT

Due to the massive increase in non-ionizing radiation emitting devices, the social concern about the possible malignancy to its exposure has increased the research interest. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) included the radiofrequency electromagnetic field (RF-EMF) of mobile phones on the category 2B as 'possibly' carcinogenic to humans. Epidemiological studies noticed a causal association between the exposure to RF-EMF and the incidence of brain neoplasm in different populations, since this is the organ with the highest specific absorption rate. The fact that so many of the ipsilateral tumors found are statistically significant with RF-EMF exposure provides weight suggesting causality. In this way, the higher the exposure (ipsilateral *vs* contralateral), the longer the cumulative exposure (hours of exposure) and the longer the latency (beyond 10 years); the greater the risk. In addition, considering together all of these parameters suggest a strong causality.

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Radiofrequency electromagnetic field; cancer; mobile phone; human; brain

Introduction

With the rise of mobile telecommunications, there has also been growing concern about its possible detrimental effects on the population. Our society is full of non-ionizing electromagnetic radiation emitting devices. In our homes, schools and places of work, in vehicles and streets, and sometimes implanted on our own body.

The greatest growth has been experienced by mobile telephony, which has become an almost indispensable object in our daily life: by the end of 2000 there were almost 500 million mobile phones worldwide (Rodríguez Gámez et al. 2005), and by the end of 2015, there were already more than 7 billion subscriptions (sim cards) to mobile phones, corresponding to a global penetration rate of 97% (ITU 2015).

Since the International Commission on Non-Ionizing Radiation Protection (ICNIRP) classified radiofrequency electromagnetic fields (RF-EMF), in the category 2B as 'Possibly' carcinogenic to humans (IARC 2013, 2019), the social concern has been sustained and the studies testing for causality have multiplied.

Many Institutions are dedicated to the strict control and regulation of electromagnetic emissions, always with a wide margin of safety. In this way, the Ministry of Energy, Tourism and Digital Agenda in Spain periodically verifies that the RF-EMF emitting devices comply with the current exposure limits published in the new directive 2013/35 of the European Union (Real Decreto 299 2016), and verifies that the exposure levels in the population are much lower than those

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recommended by the scientific agencies and committees (1 mW/cm^2) [WHO (World Health Organization); ICNIRP; FCC (Federal Communications Commission) and the IEEE (Institute of Electrical and Electronic Engineering)] (ICNIRP 1998).

However, it cannot be firmly established that continuous exposure to RF-EMF, even if the exposure levels are below to legal limits, does not cause an effect on health. Although mathematical rules governing the functioning of RF-EMFs are well known, the interaction between RF-EMF with cellular biology and the physiology of the organisms remain unclear. This circumstance makes impossible to explain the biological effects of exposure to RF-EMF accurately (CCARS 2017). In addition, the exposure limits avoid the already known thermal effects of the RF-EMF, but there is no certainty about the non-thermal effects.

Possible mechanisms of interaction of RF-EMF with living organisms were described in different studies:

- Human studies showed increased blood flow in the frontal lobe (Bhargav et al. 2015), as well as an increase in temporal lobe metabolism (Volkow et al. 2011).
- In cellular experimental studies, genotoxic effects, formation of oxygen free radicals (ROS) (Havas 2017), or activation of the cellular response to stress were observed; inducing the production of thermal shock proteins (HSP70) (Miah and Kamat 2017), as well as alterations of the cell membrane and transmembrane transmission (IARC 2013).

These effects could induce DNA damage, which would explain the possible carcinogenic action of the RF-EMF.

Therefore it is not admissible that this social concern is not studied in more depth, deepening the investigations to refine the results and the consequences since until now there is no agreed answer.

The aim of this paper is to analyze the most recent literature on the subject that concerns us to evaluate the hypothetical causal association between exposure to RF-EMF (400 MHz – 3 GHz) and its impact on the incidence of brain tumors, as well as the possible mechanisms responsible for this effect.

Materials and methods

Search strategy

A PubMed search was performed using the keywords ‘mobile phone, cell phone, cancer, health effects, electromagnetic field, human, brain’. Only articles related to effects of RF-EMF on human brain and cancer incidence were analyzed. Finally 18 articles from 65 were selected after inclusion and exclusion criteria application.

Selection criteria: inclusion

The selected articles had to fulfill two indispensable conditions related to cancer incidence:

- Published between 2009 and 2019.
- Frequency of RF-EMF between 400 MHz and 3 GHz.

Only articles of greater relevance were selected. The relevance was related to methodological quality, consistency of their results, or articles highly cited. They were divided in epidemiological and experimental.

Selection criteria: exclusion

Many of the articles were discarded because they did not provide relevant or conclusive data either because of the type or topic of the study, because they were performed on a very small sample size, due to a too short patient follow-up or due to a low methodological quality in the patients surveys on the intensity of use of the mobile phone.

Results and discussion

We seldom rely on only epidemiological studies to assess causality. Normally a combination of epidemiological studies (association), in vivo studies with test animals under carefully controlled conditions (cause/effect relationship), and in vitro studies (mechanisms) need to be considered together to determine causality. All three types of studies are readily available in the literature. All of them indicate a causal relationship between cell phone exposure and gliomas and possibly other types of tumors.

Experimental studies

The effects of RF-EMF on health were initially attributed to the production of heat, defined by the specific absorption rate (SAR). However, it has been shown that the frequencies that mobile phones emit (between 900 MHz and 2.4 GHz), and the low intensity at which they work, are not capable of increasing body temperature (Volkow et al. 2011; Lerchl et al. 2015).

Even so, this does not mean that RF-EMFs are not harmful. There are a variety of health problems that have been attributed to continued exposure to RF-EMF, such as cognitive defects, autonomic dysfunctions, increased risk of brain tumors and childhood leukemias, or the electromagnetic hypersensitivity syndrome (Belyaev et al. 2016). Regarding the latter, there are many people who have related the appearance of nonspecific symptoms such as nausea, vomiting, dizziness, or even decreased libido with a sustained exposure to RF-EMF from telephony antennas or domestic Wi-Fi equipment. The WHO has adopted the International Classification of Diseases ICD-10 Code (W90) for injury due to radiofrequency radiation.

Other studies have shown a change in the metabolism of different human tissues (Volkow et al. 2011; Bhargav et al. 2015). The brain is the organ in which, first of all, the immediate effects of acute exposure to RF-EMF are analyzed in-vivo, because it is the organ that receives more radiation, being the temporal lobe the first place (50–60% of absorbed radiation) and the frontal lobe the second place (14–18%) (Cardis et al. 2008).

Other studies showed a slight increase in the brain flow, measured in the middle cerebral artery, associated to a high increase in the flow measured in the frontal lobe as well as an increase in the metabolism of the regions closest to the position of the mobile antenna (temporal lobe) (Volkow et al. 2011).

The mechanisms by which RF-EMF interact with brain tissue to increase its metabolism are still unknown, although it has been hypothesized that it could be due to an influence on membrane permeability, calcium flux, cellular excitability, or in the release of neurotransmitters (Volkow et al. 2011). What is clear is that these experiments show the brain as a tissue sensitive to RF-EMF emitted by the mobile phone.

To further analyze the possible interactions between RF-EMF and the production of cancer (specifically gliomas), different studies were carried out on both human and animal cell lines that analyze the genotoxic effects of these radiations (Ruediger 2009; Bhargav et al. 2015; Lerchl et al. 2015; Su et al. 2016).

In the study by Lerchl et al. (2015) it was demonstrated that continued exposure to RF-EMF at SAR levels lower than those legally established (0.04 W/Kg, 0.4 W/Kg and 2 W/Kg) throughout life (from day 6 after conception) of rats treated with the carcinogen ENU (N-ethyl-N-nitrosurea)

produced a significant increase in the incidence of adenomas and carcinomas compared to the incidence obtained in the control group. The findings reported by these authors were:

- Lungs: Almost a double increase in bronchi alveolar carcinomas at low SAR levels (0.04 W/Kg and 0.4 W/Kg).
- Liver: More than double incidence of hepatocellular carcinoma at SAR levels of 0.4 W/Kg and 2 W/Kg.
- The number of animals with lymphoma was increased 2.5 times at SAR levels of 0.4 W/Kg).

However, it is not known at what time of co-exposure to RF-EMF and ENU take place the promotion in the formation of tumors. In addition, the results in animals are not fully extrapolated to humans, so, despite having observed a causal relationship between the RF-EMF and the production of cancer, these conclusions have to be analyzed with caution.

Other studies carried out on human cell lines showed genotoxic effects of RF-EMF (Ruediger 2009; Su et al. 2016), specially in the most sensitive, the stem cells (Bhargav et al. 2015). Stem cells are not able to adapt to a chronic exposure, therefore defects in DNA repair that could produce chromosomal alterations appears and eventually could lead to cancer induction. From the observed data, different mechanisms of genotoxicity of the RF-EMF have been proposed (Ruediger 2009):

- Thermal effect: Few years ago it was thought that this effect was the only mechanism of damage. However, it only occurs at high SAR levels, which is why it is not relevant in the current study (Volkow et al. 2011; Lerchl et al. 2015).
- ROS formation and stress response (Blank 2012; Havas 2017).
- DNA (double or single) strand break.
- Defects in DNA repair systems induced by RF-EMF: It has been postulated that RF-EMF could inhibit the endogenous formation of the 53BP1 error repair protein (tumor suppressor TP53 binding protein 1) as well as induce the condensation of chromatin, making it difficult to access it by repair proteins (Bhargav et al. 2015).
- Induction of the genotoxic action of various chemical and physical carcinogens due to exposure to RF-EMF (epigenetic effect) (Lerchl et al. 2015).

On the other hand, the study of Su et al. (2016) carried out exposing different cell lines of the central nervous system to RF-EMF at a frequency of 1800 MHz during 24 h did not observe any alteration in cellular proliferation, viability, or progression in the cell cycle.

The relationship between cancer and exposure to RF-EMF and the mechanisms of action reported, despite the results discussed above, is not fully demonstrated as many of the authors claim that the results obtained are highly influenced by a multitude of variables and factors, such as the different emission characteristics in the different studies or the difficulty in the reproducibility of the real emission pattern, as well as many others that are not yet known or cannot be controlled. Due to these reasons, the results obtained have to be analyzed with caution.

On the other hand, these positive results reported establish the basis that have to be taken into account as a real evidence of a possible carcinogenic effect of RF-EMF on the health of living beings, which should be studied more thoroughly.

Epidemiological studies

Since 2011, ICNIRP considered RF-EMF within the group 2B as a 'possible human carcinogen' (Carlberg and Hardell 2014). This decision was based mainly on two sets of case-control studies on the risk of brain tumors in humans (Hardell et al. 2006, 2011). They found a statistically significant association between the use of the mobile phone (for more than 10 years and more than 74 h of accumulated use) and the appearance of different malignancies:

- Glioma: Odds ratio (OR) = 2.5; 95% confidence interval (CI) = 1.8–3.4 (115 cases and 96 controls).
- Astrocytoma: OR = 2.5; 95% CI = 2.0–3.8 (102 cases and 96 controls) (Ca/Co).
- All malignant tumors: OR = 2.7; 95% CI = 1.9–3.7 (124 cases and 96 controls).
- Increased risk of incidence of malignant tumors associated with ipsilateral exposure to the mobile phone with an OR = 1.8; IC95% = 1.4–2.4.

The hypothesis investigated by the different epidemiological studies was the possible causal association between exposure to RF-EMF and the increase in the incidence of cancer. This hypothesis was supported by the experimental studies discussed above.

In particular, most of the information found was related to brain tumors (both benign, such as meningioma or acoustic neuroma; and malignant tumors, especially glioma), which is why the literature review has been focused on these cases.

The common feature that has been found in most of the articles reviewed is that by increasing the intensity or latency of use (measures in accumulated hours of use or in previous years of use respectively), the risk increases in the same way. An association was also found between the preferred side of use and the location of the tumor, with greater risks for ipsilateral exposure to the side of the tumor.

Exposure to RF-EMF and risk of glioma

As shown in Table 1, an increase in the risk that increases directly proportional to the intensity of use was found (either measured in accumulated hours or in years of latency of use); as well as an increased risk in ipsilateral versus contralateral use. All but one of the data points indicates a statistically significant association for ipsilateral tumors. This would tend to support a causal association since they are different studies.

Regarding the location of the tumor, the temporal lobe and the frontal lobe are the locations that receive the most energy under exposure to the RF-EMF (Cardis et al. 2008). The epidemiological data support this statement, showing an OR of 1.87 (1.09–3.22) in the INTERPHONE study (Cardis et al. 2010), and an OR of 1.87 (1.09–3.22) in the CERENAT study (Morgan et al. 2015) when the location of the tumor was in the temporal lobe.

The data that best reflect the increase in risk with the increase in the intensity of use are those reported by Hardell and Carlberg (2015), in which an OR of 1.5 (1.2–1.8) with anuse between 5 and 10 years was observed. These authors found an OR of 3.0 (1.7–5.2) when the use was greater than 25 years. The intensity estimation of use by the accumulated hours, reported an OR of 1.3 (1.05–1.5) for those users with less than 122 h of accumulated use and an OR of 2.2 (1.7–2.9) for those users with more than 1486 h of accumulated use.

In addition, Carlberg and Hardell (2017) concluded that RF-EMF radiation should be regarded as a human carcinogen causing glioma after the application of Bradford Hill's viewpoints from 1965 on association or causation of glioma risk and the use of mobile phone. They found clear consistency in the increased risk with latency and clear specificity in the increased risk with tumor location in the temporal lobe.

Exposure to RF-EMF and risk of acoustic neuroma

As shown in Table 2, an increase in relative risk when the intensity of use increases was observed after analyzing the data obtained from the INTERPHONE study (Cardis et al. 2011). The OR increases from 1.32 (0.88–1.97), in those individuals with up to 1 year of previous use, to an OR of 1.93 (1.10–3.38) in those with 10 years of previous use; both with more than 1640 accumulated hours. Similarly, an increased risk of ipsilateral versus contralateral exposure was observed for any intensity-of-use group.

However, most of the results shown in Table 2 must be interpreted with caution since either the confidence intervals contain the unit, or they are too large to be statistically significant.

Table 1. Exposure to RF-EMF and relative risk of glioma incidence.

Reference	Study name	Time of phone use	Tumor location and/or size of phone use	OR	CI 95%	Ca/Co
Cardis et al. 2010	INTERPHONE 2010 (13 countries) (Participants: 30–59 years old)	>1640 hour	All locations	1.40*	1.03–1.89	210/154
			Ipsilateral	1.96*	1.22–3.16	nd
			Contralateral	1.25	0.64–2.42	nd
		>1640 hours (Up to 4 years of latency prior to inclusion in the study)	nd	3.77*	1.25–11.4	nd
		>1640 hours	Temporal lobe (no preferred side of phone use)	1.87*	1.09–3.22	nd
		Rest of groups (5–9 years and >10 years)	nd	nd	1	nd
Hardell and Carlberg 2015	HARDELL 2015	>1 year of previous use	nd	1.3*	1.1–1.6	945/2148
		5-10 years of previous use	nd	1.5*	1.2–1.8	301/688
		10-15 years of previous use	nd	1.4*	1.1–1.9	211/476
		>25 years of previous use	nd	3.0*	1.7–5.2	29/33
		>1 year of accumulated time	Ipsilateral	1.8*	1.4–2.2	592/920
			Contralateral	1.1	0.8–1.4	316/729
		5-10 years of accumulated time	Ipsilateral	1.9*	1.4–2.5	187/289
			Contralateral	1.4	0.9–1.8	106/238
		10-15 years of accumulated time	Ipsilateral	1.7*	1.2–2.3	131/225
			Contralateral	1.3	0.9–2.0	74/152
		>25 years of accumulated time	Ipsilateral	4.6*	2.1-10	19/13
			Contralateral	3.2*	1.2–8.6	10/9
		1-122 accumulated hours	nd	1.3*	1.05–1.5	340/920
		>1486 accumulated hours	nd	2.2*	1.7–2.9	228/320
		Start age of use <20 years	All locations	1.8*	1.2–2.8	60/93
			Ipsilateral	2.3*	1.3–4.2	39/38
			Contralateral	1.9	0.9–3.7	22/28
Morgan et al. 2015	CERENAT 2014	>896 accumulated hours (>1 year from first use)	nd	2.89*	1.41–5.93	nd
		>896 accumulated hours (>2 year from first use)	nd	3.03*	1.47–6.29	nd
		>896 accumulated hours (>5 year from first use)	nd	5.30*	2.12–13.23	nd
		>896 accumulated hours (4 years of latency prior to inclusion)	nd	3.77*	1.25–11.4	23/8
		>896 accumulated hours	Temporal lobe (no preferred side of phone use)	1.87*	1.09–3.22	nd
			Ipsilateral	2.11	1	nd
			Contralateral	nd	<1	nd
			Temporal lobe	3.94	1	nd
			Frontal lobe	1.87	1	nd

OR: Odds ratio. CI: Confidence interval. Ca/Co: Cases/Controls. nd: No data.
* This data indicates a statistically significant association.

Table 2. Exposure to RF-EMF and relative risk of acoustic neuroma incidence.

Reference	Study name	Cumulative use (hours)	Tumor location and or size of phone use	OR	CI 95%	Ca/Co
Cardis et al. 2011	INTERPHONE 2011	>1640 (1 year)	All locations	1.32	0.88–1.97	77/107
			Ipsilateral	2.33*	1.23–4.40	47/46
			Contralateral	<1	nd	nd
		>1640 (5 years)	All locations	2.79*	1.51–5.16	36/31
			Ipsilateral	3.53*	1.59–7.82	27/22
			Contralateral	1.69	0.43–6.69	6/5
		>1640 (10 years)	No distinction of laterality	1.93*	1.10–3.38	37/37
			Ipsilateral	3.74*	1.58–8.83	28/17

OR: Odds ratio. CI: Confidence interval. Ca/Co: Cases/Controls. nd: No data.
* This data indicates a statistically significant association.

The rest of the variables analyzed in this study had an OR <1, so they have not been taken into account.

Exposure to RF-EMF and risk of meningioma

As shown in Table 3, as in the previous cases, we can observe, with the data extracted from the INTERPHONE study (Cardis et al. 2010), an increase in the relative risk that increases with the increase in the intensity of use and with the use preferably ipsilateral versus the contralateral location of the tumor. However, in the CERENAT study (Morgan et al. 2015), paradoxically, a decrease in intensity was observed when the latency years increased for the same intensity (in hours) of use, which is attributed to a smaller number of participants. In addition, the results are difficult to interpret since the confidence intervals were either too broad or contained the unit.

On the other hand, depending on the location of the tumor regardless of the preferred side of use, no increase in risk was observed.

Exposure to RF-EMF and risk of brain tumors (any type)

Chapman et al. (2016) studied, in an Australian cohort, the influence of mobile phone use and the incidence of brain tumors. Among all patients diagnosed with a brain tumor in Australia between 1982 and 2012, a comparison was made between the annual incidence of cancer and the expected incidence if the use of the mobile phone (which reaches a user rate of approximately 90% in this country) had a statistically significant effect on the production of brain neoplasms; assuming a Relative Risk (RR) for the use of the mobile phone of 1.5 for a moderate use and 2.5 for a very intense use (> 896 of cumulative hours).

This study was conducted separating 5 age groups (between 20–84 years, between 20–39 years, between 40–59 years, between 60–69 years, and between 70–84 years) and distinguishing between men and women.

Table 3. Exposure to RF-EMF and relative risk of meningioma incidence.

Reference	Study name	Cumulative use (hours)	Tumor location and/or size of phone use	RR	OR	CI 95%	Ca/Co
Cardis et al. 2010	INTERPHONE 2010	>1640	All locations	1.15	nd	0.81–1.62	130/107
			Ipsilateral	1.45	nd	0.80–2.61	nd
			Contralateral	<1	nd	nd	nd
			4 years prior to inclusion	4.8*	nd	1.49–15.4	22/5
			Depending on the location of the tumor	<1	nd	nd	nd
Morgan et al. 2015	CERENAT 2010	>896 (>1 year)	nd	nd	2.57*	1.02–6.44	nd
		>896 (>2 years)	nd	nd	2.40	0.96–6.05	nd
		>896 (>5 years)	nd	nd	1.44	0.43–4.8	nd

RR: Relative risk. OR: Odds ratio. CI: Confidence interval. Ca/Co: Cases/Controls. nd: No data.
* This data indicates a statistically significant association.

The expected incidences were significantly greater than the incidences obtained in all age groups and for both sexes, so it was assumed that there was no evidence that the use of mobile phones increased the incidence rate of brain tumors in this population.

The only group whose incidence rate increased was the oldest one (70–84 years), but this was attributed to an improvement in diagnostic techniques since the population over 70 years old is the one with the least prevalence of mobile phone use.

In this ecological study it was assumed that the use of the mobile phone was the same in all age groups and also in men and women.

Regarding all the previous studies, the results that had an OR <1 or a 95% Confidence Interval (95% CI) containing the unit have not been taken into account due to their little statistical relevance since the hypothesis that RF-EMF plays a protective role in the production of cancer (RR <1) was taken as implausible and was due to methodological difficulties in the selection (selection bias) and follow-up of study patients, as well as confusion factors or problems in the elaboration or in the answers to the interviews carried out to analyze the use of the mobile phone.

The fact that so many of the ipsilateral tumors found are statistically significant with RF-EMF exposure provides weight suggesting causality. In this way, the higher the exposure (ipsilateral *vs* contralateral), the longer the cumulative exposure (hours of exposure) and the longer the latency (beyond 10 years); the greater the risk. In addition, considering together all of these parameters suggest a strong causality.

Conclusions

This review reinforces the hypothesis of the causal association between continuous exposure to RF-EMF, between 400 MHz – 3 GHz, and the appearance of brain tumors showing clear evidences on brain cancer induction. The circumstances in which this causal association is more significant are in cases with a high latency of mobile phone use or those with a very intense use. In addition, the effects of the exposure may be different in sick or healthy individuals, or they could interact with the medication that the subject is taking at that moment (epigenetic effect).

On the other hand, scientific information about RF-EMF is extremely dispersed in terms of the type of tests carried out, the parameters studied, the experimental procedures used, the end points evaluated, etc., making comparisons practically impossible and hindering the achievement of definitive conclusions.

The exposure period, to produce the suspected carcinogenic effect by RF-EMF, must be produced for long periods of time. Studies reported are currently limited in that regard.

It is therefore necessary further studies, with standardized protocols and very long follow-up, with a strict selection of cases, to reach relevant conclusions and adopt measures accordingly if necessary.

Disclosure Statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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