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Occupational exposure to radio frequencies in the development of head and neck cancer: a systematic review of cohort studies

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Abstract

This systematic review aimed to summarize published data on cohort studies investigating the association between the occupational exposure to radio frequencies and clinical outcome of head and neck cancers.
We retrieved the relevant articles from PubMed and SCOPUS databases. Studies were selected using specific inclusion and exclusion criteria: study design, professional exposure and type of head and neck cancers.
Twenty-nine articles were included in the present analysis.
Occupational exposure to radio frequencies might be associated with the development to head and neck cancer. No consistent evidences generally were found in the review. An interesting, even if weak, association with incidence of larynx tumor was found in three studies: RR=1.46 (95%CI: 1.05-2.43) for all electronic workers; RR=1.4 (95%CI: 1.2-1.6) for male electrical workers; and a significant SIR for electrical workers =1.39 (95%CI: 1.08-1.76).

Keywords: *head and neck, cancer, occupational exposure, electromagnetic, workers, microwave, cohort.*

1.Introduction

The use of electricity is an integral part of daily life. All times in which flows an electrical current, electric and magnetic fields are created near the lines which carry electricity and close to the equipment. The increase in high frequency voltage transients sources, especially in urban areas from cell phones and towers, terrestrial antennas, wi-fi and wi-max systems, broadband internet over power lines, and personal electronic equipment, suggests that like the 20th century EMF (Electro Magnetic Field) epidemic, we may witness a 21st century epidemic of morbidity and mortality underway caused by electromagnetic fields [1].

In fact, since the late '70s, research has placed the question whether exposure to electric and magnetic fields at high, medium or very low frequency (Extremely Low Frequency, ELF) could result in adverse health effects and detail if that may increase the risk of cancer. Wertheimer and Leeper in 1979 suggested the possibility of a relationship between childhood leukemia and electromagnetic fields [2].

Since then, numerous studies have been carried out about the epidemiology of both electric and magnetic fields impact and research of the effects in vitro and in vivo, as well as their biological mechanisms of action that helped to solve important questions [3,4]. This led in 2002 the IARC (International Agency for Research on Cancer, part of the World Health Organization, WHO) to include the ELF magnetic fields in the category of substances "possible carcinogenic to humans" [5].

WHO has regularly published documents on this subject, providing an important scientific monitoring and has also recently finished a critical review of the implications of ELF fields on human health. In 2007, findings about the health effects of ELF fields conducted by IARC (published in 2002), and the International Commission on Non-Ionizing Radiation Protection

(ICNIRP), (published in 2003) [6] were collected: there is limited evidence of carcinogenicity in humans of ELF electric fields at levels to which generally the population is exposed and the conclusion published in 2002 by the IARC, which classified the ELF magnetic fields in the category " possible carcinogenic for man ", remains valid.

Among the adverse effects associated with possible exposure to ELF magnetic fields the following have been specified: childhood and adult cancers, depression, suicide, cardiovascular diseases, reproductive disorders, developmental problems, immunological disorders, neuro-behavioral and neurodegenerative diseases (Alzheimer). WHO concluded that the scientific data supporting an association between exposure to ELF magnetic fields and all health effects are weaker than those related to childhood leukemia, and in some cases, data suggest that the fields do not cause the effects under discussion (eg, cardiovascular disease or breast cancer).

It is thus clear that this issue needs a further investigation. Therefore, the aim of this study is to conduct a systematic review of cohort studies in order to evaluate a relationship between occupational radiofrequency exposure and tumoral diseases in head and neck area among workers exposed for long time to electromagnetic fields.

2. Materials and Methods

The systematic review was conducted according to the PRISMA statement [7].

Research was realized consulting medical electronic databases: PubMed (including Medline, Medical Literature analysis and Retrieval System Online) and Scopus. The research algorithms used in Pubmed and Scopus were:

1. “radiofrequency” AND “microwave” AND “electromagnetic” AND “cancer”;
2. “electromagnetic field” AND “cancers” AND “workers”;
3. “interphone study” AND “head neck cancer”.

The research was conducted including published article until 1st October 2013. The first phase was performed analyzing the title and abstract of articles; the second step included that each paper was independently revised by two different researchers followed inclusion criteria and data extraction. Data collected were entered into a database.

Inclusion criteria

The investigator evaluated the inclusion criteria, performed the data extraction and assessed the quality. Data extraction and quality by two reviewers were performed again for establishing inter-rater reliability and avoiding data entry errors. In case of disagreement between the two reviewers, a senior researcher was consulted.

The following criteria are used to distinguish between observational studies that are eligible for inclusion in the review and those that are not:

- study designs: cohort studies;
- types of head/neck tumors (brain, oral cavity and pharynx, larynx, ocular melanoma/eye tumor);
- studies on electrical workers exposed to electromagnetic field, in particular: electricians, electric machine operators/fitters/repairmen, linemen, cable jointers, engineers, technicians, military personnel, welders, plumbers and sheet-metal workers;
- papers published in English and Italian languages (native tongue of the authors).

In the present review the term “published article” means that books chapter, posters and conference proceedings were excluded, according to Easterbrook et al. (1991) [8]. All the studies were listed and organized using the software JabRef 2.7.2.

Data extraction and quality

The information extracted from each reviewed study included: first author name, publication year, study nationality, investigation period, type of occupation, type of cancer, exposure measures, epidemiological measures (PMR=proportionate mortality ratio with 95%CI, PRR=proportional registration ratio, RR= Relative Risk with 95%CI, SIR=standardized incidence ratio with 95%CI, SMbR= standardized morbidity ratio with 95%CI, SMR=standardized mortality ratio with 95%CI).

To better assess the quality of each cohort study included in the systematic review the score sheet available for observational studies according to La Torre et al. [9] was applied. The information collected is summarized in table 1.

3.Results

The literature search identified 615 studies published since 1983. Flow chart of the study selection process is shown in Figure 1. The first algorithm found 195 studies on PubMed and 88 on Scopus, the second one 137 and 188 and the third one four and three. Of the 615 studies reviewed:

- 184 are duplicated or not scientific works (congress proceedings, posters, letters, book chapters, etc.).
- 376 are excluded because not related to the matter of the study or because are in different languages from Italian or English;
- 20 resulted systematic or narrative review.

In the review 35 observational studies were found, of which 20 cohort studies [10-29]. From the analysis of the references of the papers evaluated, 9 articles were added [30-38]. So, twenty-nine articles were finally included in the present analysis.

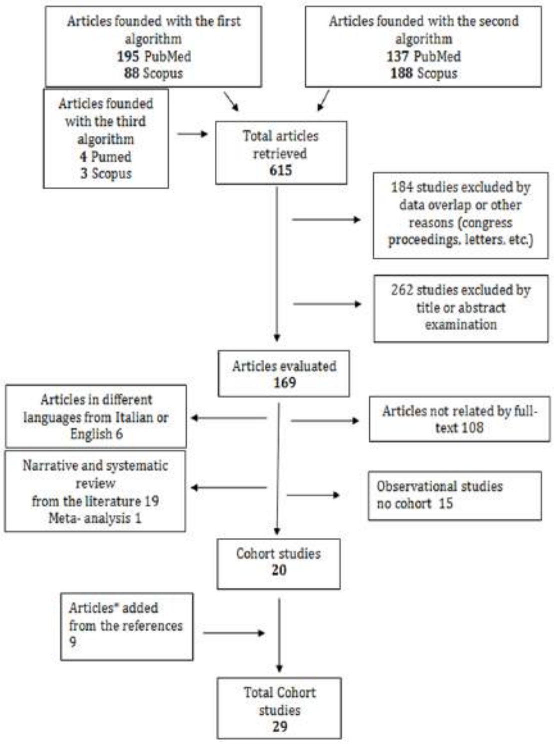
Description of the studies

The results of the 29 cohort studies investigated the relation of our interest from 1920 to 2009 (Table 1). The quality of the studies was sufficient: the median of all studies included was 8.5 points on 13.5 (63%), with min=6 points and max=10 points. The study population ranged from 1035 [31] to 2,800,000 [11] people.

As exposures, both pulsed and non-pulsed high frequency electromagnetic fields from different sources were defined. In addition, the studied populations were represented by different typologies of workers, such as electrical workers and welders, radio and telegraph operators, Navy Electronic technician.

The findings are discussed in the following paragraphs according to the neoplasms localizations and outcomes (cancer incidence diagnosis or cancer mortality).

Figure 1. Flow chart of the bibliographic research.



Brain cancer

The majority of the articles retrieved is concerning the brain cancer. The median score quality was sufficient: 8..3 points on 13.5. As shown in table 2, we found for brain cancer that RR (Relative Risk) ranged between 0.8 (95%CI: 0.5-1.1) for a magnetic field of 0.53 μT, to 0.68 (95%CI: 0.33-1.40) for a magnetic field up to 20 μT. Concerning the SIR (Standardized Incidence Ratio), we found values of 0.79 (95%CI: 0.6-1.0) and 1.09 (95%CI: 0.90-1.41); the SIR adjusted for age was 1.1 for engineers/technicians and 0.9 for electrician/electronic workers (both the previous values did not reach the statistical significance).

Using the SMR (Standardized Mortality Ratio) as epidemiological measure, the minimum value was 0.53 (95%CI: 0.21-1.09) in electrical workers, while the highest value was 1.13 (95%CI: 0.69-1.75). It is interesting to note that the Observed/Exposed ratio for military personnel [12] had shown a value of 1.91 (95%CI: 1.08-3.47), and is the only study in which the relation between the exposure and the occurrence of this type of cancer reached significant results; in addition, the PMR (proportion mortality ratio) for electrical and power station workers showed a significant value of 1.23.

Cancer of the Larynx

Table 3 shows the incidence and mortality for other cancer localizations. The median quality score of the studies was sufficient: 8.3 points on 13.5.

The developing of cancer in this area was assessed using seven studies. Among the three studies that reported the RR, two found statistically significant values: RR=1.46 (95%CI: 1.05-2.43) for all electronic workers; RR=1.4 (95%CI: 1.2-1.6) for male electrical workers. One study showed a significant SIR for electrical workers (1.39; 95%CI: 1.08-1.76).

Ocular melanoma/eye tumor, pharynx and oral cavity

The median quality score of the studies was more than enough: 9 (67%) points on 13.5. The RR for ocular melanoma ranged from 1.1 (95%CI: 0.9-1.5) in men with high exposure, to 1.3 (95%CI: 0.8-2.0) in women with the same risk of exposure. As far as concerns other measures, none of them showed statistically significant results. Among the electrical manufacturing workers the RR for the development of the cancer of the pharynx and oral cavity was 0.53 (95%CI: 0.31-0.89) and in navy electronic technicians 0.62 (95%CI: 0.35-1.08). The SIR for electrical workers was 0.91 (95%CI: 0.7-1.2) for men and 0.5 (95%CI: 0.1-1.9) for women.

Two studies evaluated the risk for pharynx localization only: for electrical manufacturing workers we found a RR of 2.3 (95%CI: 1.11-4.79).

4.Discussion

Several studies have addressed the question of whether exposure to ELF electromagnetic fields increased the risk of cancer. The IARC has classified this agent as possible human carcinogen (Group 2B), based on limited evidence of an increased risk of childhood leukaemia for exposure above 0.4 µT [39]. In the review of epidemiologic studies conducted by Elwood et al. in 1999 [40], the conclusion is that although correlations between exposure and certain cancers can be observed, these are weak (probably due to statistical fluctuations), inconsistent (different studies show opposite results regarding specific cancers), and overall did not show an increased risk with the exposure.

Referring to studies not on the general population, but on workers exposed to electromagnetic fields, the evidence is heterogheneous. One of the early studies is carried out by Milhan in 1985 [14].

He classified the occupational activities under the supposed magnetic field exposure and observed an increased risk of leukemia among workers, defined as "electric". However, in that analysis, there was a strong bias measurement, having defined exposure to electromagnetic fields through the employment activity.

Table 1. Characteristics of the collected cohort studies.

Rif.	Authors	Country	Period of investigation	Explorer	Localization of tumor	Quality (max=10)
10	Sahl et al. 1993	USA	1960-1988	Electrical workers	Brain	9.5
11	Guenel et al. 1993	Denmark	1970-1987	Industry-occupation workers	Brain	8
12	Szmigielski et al. 1996	Poland	1971-1985	Military personnel	Brain	7.5
13	Harrington et al. 1997	UK	1972-1991	Employees of the Central Electricity Generating Board	Brain	10
14	Milham et al. 1985	USA	1950-1982	Electrical and power station workers	Brain	7
15	Degrave et al. 2008	Belgium	1963-1994	Professional male military personnel exposed to Hawk radar system	Brain	9
16	Floderus et al. 1999	Sweden	1971-1984	Electrical workers and welders	Brain	9
34	Groves et al. 2002	Korea	1950-1954	Navy Electronic technician	Brain	10
17	Håkansson et al. 2002	Sweden	1985-1994	Industrial welding workers	Brain	9
21	Johansen et al. 2007	Denmark	1900-1993	Electrical workers	Brain	7
18	Juutilainen et al. 1990	Finland	1971-1980	Electrical workers with probable exposure	Brain	8
19	Sorahan et al. 2001	UK	1973-1997	Electrical workers	Brain	10
20	Johansen et al. 1998	Denmark	1900-1981	Electrical workers	Brain	9.5
21	Johansen et al. 2007	Denmark	1900-1993	Electrical workers	Brain	7
27	Tynes et al. 1992	Norway	1960-1970	electrical workers	Brain	9
28	Tynes et al. 1994	Norway	1920-1991	electrical workers	Brain	8.5
30	Tynes et al. 1996	Norway	1920-1980	radio and telegraph operators	Brain	8.5
31	McLaughlin et al. 1987	Sweden	1961-1679	Electrical workers	Brain	6
37	Vågerö et al. 1985	Sweden	1958-1979	Industrial welding workers	Brain	6
22	Baris et al. 1996	Canada	1970-1988	Workers employed in electric company	Brain	8
23	Kelsh et al. 1997	USA	1960-1991	Plant operations	Brain	8
35	Morgan et al. 2000		1976-1996	Electrical workers	Brain	7
24	Nichols et al. 2005	UK	1973-2002	Electriciy generation and transmission workers	Brain	8
32	Olin et al. 1985	Sweden	1930-1979	Electrical workers	Brain	7.5
25	Röösli et al. 2007	Switzerlan d	1972-2002	Railroad workes	Brain	8.5
26	Savitz et al. 1995	USA	1950-1986	Electrical workers	Brain	9.5
33	Coggon et al. 1986	USA	1975-1980	Electrical and electronic workers	Larynx	8.5
16	Floderus et al. 1999	Sweden	1971-1984	Electrical workers and welders	Larynx	9
36	Vågerö et al. 1983	Sweden	1961-1973	Electrical manufacturing workers	Larynx	8
20	Johansen et al. 1998	Denmark	1900-1981	Electrical workers	Larynx	9.5

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37	Vågerö et al. 1985	Sweden	1958-1979	Industrial welding workers	Larynx	6
24	Nichols et al. 2005	UK	1973-2004	Electriciy generation and transmission workers	Larynx	8
38	Vågerö et al. 1990	UK	1971-1978	Electrical and electronic workers	Ocular melanoma/eye tumour	9
16	Floderus et al. 1999	Sweden	1971-1984	Electrical workers and welders	Ocular melanoma/eye tumour	9
24	Nichols et al. 2005	UK	1973-2004	Electriciy generation and transmission workers	Ocular melanoma/eye tumour	8
26	Savitz et al. 1995	USA	1950-1986	Electrical workers	Ocular melanoma/eye tumour	9.5
12	Szmigielski et al. 1996	Poland	1971-1985	Military personnel	Oral cavity and pharynx	7.5
15	Degrave et al. 2008	Belgium	1963-1994	Professional male military personnel exposed to Hawk radar system	Oral cavity and pharynx	9
16	Floderus et al. 1999	Sweden	1971-1984	Electrical workers and welders	Oral cavity and pharynx	9
34	Groves et al. 2002	Korea	1950-1955	Navy Electronic technician	Oral cavity and pharynx	10
36	Vågerö et al. 1983	Sweden	1961-1973	Electrical manufacturing workers	Oral cavity and pharynx	8
20	Johansen et al. 1998	Denmark	1900-1980	Electrical workers	Oral cavity and pharynx	9.5
37	Vågerö et al. 1985	Sweden	1958-1979	Industrial welding workers	Oral cavity and pharynx	6
24	Nichols et al. 2005	UK	1973-2004	Electriciy generation and transmission workers	Oral cavity and pharynx	8
36	Vågerö et al. 1983	Sweden	1961-1973	Electrical manufacturing workers	Pharynx	8
24	Nichols et al. 2005	UK	1973-2006	Electriciy generation and transmission workers	Pharynx	8

Savitz et al. [41] shows the evidence gathered up to 1993; they highlighted some procedural problems in the conduct of studies, more or less important, not only attributable to the measurement of exposure but also to poor control for possible confounding factors. Moreover, as regards the results Savitz et al. illustrate the heterogeneity observed. Although many studies reveal an association between occupational exposure to electromagnetic fields with leukemia and myeloid leukemia and brain tumors [42,43], other cohort studies do not show the same level of evidence and others show more or less significant associations with other types of cancers, melanomas, lymphomas and breast cancer in males [14, 27, 44-47]. Occupational studies that takes into account the weaknesses of previous work, and therefore the effects of potential confounders (smoking, benzene, ionizing radiation, pesticides and solvents) show an increased risk of cancer in exposed workers, and here also show no uniqueness in form tumor: Flodeurs et al. [48] indicate an increased risk of lymphocytic leukemia with increasing level of exposure to electric and magnetic extremely low frequency (0.16-0.19 µT: OR=1.1 95%CI: 0.5-2.3; 0.20-0.28 µT: OR=2.2 95%CI: 1.1-4.3; and > 0.28 µT: OR=3.0 95%CI: 1.6-5.8). Moreover, Thèriault et al. (49) observed significant results for a median cumulative exposure of 3.1 µT /year and acute lymphoid leukemia (OR=2.41; 95%CI: 1.07-5.44) and acute myeloid leukemia (OR=3.15; 95%CI: 1.20-8 .27) which is not observed by Flodeurs et al. [16]. The work of Savitz and Loomis published in the same period shows contrasting results compared to the previous two works, and does not support any association between occupational exposure to magnetic fields and leukemia, although does not exclude a link with brain tumors [26].

Table 2. Brain cancer incidence and mortality of the collected studies.

Authors	Outcome	Epidemiologic Measures	Main Results	Quality of the study
Johansen et al. 1998	incidence diagnosis	SIR	Men=0.79 (0.6-1.0) Women=1.33 (0.7-2.2)	9.5
Tynes et al. 1992	incidence diagnosis	SIR	1.09 (0.90-1.41)	9
Tynes et al. 1994	incidence diagnosis	SIR	0.88 (0.47-1.50)	8.5
Tynes et al. 1996	incidence diagnosis	SIR	1.00 (0.3-2.3)	8.5
McLaughlin et al. 1987	incidence diagnosis	SIR adjusted for age and region	engineers/technicians=1.1 P>0.05; electricians/electronic workers= 0.9 p>0.05	6
Vågerö et al. 1985	incidence diagnosis	SMbR	1.0 (0.3-2.3)	6
Hakansson et al. 2002	incidence diagnosis	RR	Low exposure <0.164 T: reference group; Medium Exposure 0.164-0.25 T: Men=0.9 (0.7-1.1) Women=1.2(0.8-1.7); High Exposure 0.25-0.53 T: Men=1.2 (0.9-1.6) Women= 1.6 (1.0-2.4); Very High Exposure >0.53 T: Men= 0.8 (0.5-1.1) Women=1.9 (0.9-3.9).	9
Johansen et al. 2007	incidence diagnosis	RR	Medium exposure 0.1-0.99 T: Men= 0.80(0.47-1.37), Women=1.37(0.51-3.69). High exposure -1≥25), Women=0 no cases.	7
Juutilainen et al. 1990	incidence diagnosis	RR	possible exposure vs not exposure: RR= 1.31 (0.7;2.3) probable exposure vs not exposure: RR= 1.29 (1.0;1.6)	8
Floderus et al. 1999	incidence diagnosis	RR	Medium Exposure 0.084-0.115 T: Men=1.1 (1.0-1.2) Women=1.3 (0.8-2.1); High Exposure ≥ n T: Men=1.1 (1.0-1.2)Women= 1.3 (0.8-2.0).	9
Guenel et al. 1993	incidence diagnosis	Obs/expected CI95%	Magnetic intermittent: Men= 0.94(0.85-1.05); Women= 1.07 (0.93-1.23); Magnetic continuosly: Men=0.69 (0.44-1.04); Women=1.23(0.56-2.34)	8
Szmigielski et al. 1996	incidence diagnosis	OER (observed/exposed ratio)	1.91 (1.08-3.47)	7.5
Harrington et al. 1997	mortality	OR (Odds Ratio) CI95%	Geometric mean, cumulative exposure: 0.0-2.3 T, year: OR =1; 2.3-3.7 T, year : OR =1.54 (0.87-2.71); >3.7 T, year: OR=0.77 (0.40-1.47).	10
Milham et al. 1985	mortality	PMR *100	1.23 p<0.05	7
Degrave et al. 2008	mortality	ReR (Rate Ratio) CI95%	2.71 (0.42-17.49)	9
Groves et al. 2002	mortality	RR	0.65 (0.43-1.01)	10
Sahl et al. 1993	mortality	Mantel Haenzel Rate Ratio CI95%	electrical workers 1.09 (0.44-2.69); retired electrical workers 0.62 (0.20-1.94)	9.5
Sorahan et al. 2001	mortality	RR	0-2.4 T, year: reference group; 2.5-4.9 T, year: RR=0.88 CI(0.53-1.45); 5-9.9 T, year: RR=0.65 CI(0.41-1.04); 10-19.9 T, year: RR=0.68 CI(0.42-1.11); >=20 T, year: RR=0.68 CI(0.33-1.40)	10
Baris et al. 1996	mortality	SMR	1.13 (0.69-1.75)	8
Kelsh et al. 1997	mortality	SMR	0.99 CI(0.20-2.89)	8
Morgan et al. 2000	mortality	SMR	0.53 (0.21-1.09)	7
Nichols et al. 2005	mortality	SMR	Men=0.95 (0.79-1.14); Women= 0.75 (0.20-1.92)	8
Olin et al. 1985	mortality	SMR	1.0 CI (0.1-3.7)	7.5
Röösli et al. 2007	mortality	SMR	Lowland train drivers 0.64(0.23-1.79); Shunting yard engineers 1.54 (0.52-4.54); Train attendants 1.28 (0.58-2.86); Alpine train drivers (no cases)	8.5
Savitz et al. 1995	mortality	SMR	0.95 (0.81-1.12)	9.5

PMR: proportionate mortality ratio, observed/expected

PRR: proportional registration ratio (proportion of cancer cases in a worker group/ proportion of cases in other groups)

RR: Relative Risk with CI95%

SIR: standardized incidence ratio with CI95%

SMbR: standardized morbidity ratio with CI95%; SMR: standardized mortality ratio with CI95%;

A study conducted in 1996 on a sample of Polish soldiers exposed versus not exposed to radio waves, shows a significant increase in tumors: chronic myelocytic leukemia (Observed / Expected Ratio = 13.9), acute myeloblastic leukemia (OER=8.62) and non-Hodgkin's lymphomas (OER=5.82), although this study does not accurately explain how it was measured exposure [12].

The current review has several limitations. First of all, the measures of exposition to electromagnetic field in each study are different and evaluated for different occupational exposure or type of work. In addition, the epidemiological measures are quite different for each study different sample sizes were investigated. Therefore, the sources of heterogeneity in this review are several. Despite these limitations, it has be found an interesting even if weak association with larynx tumor and electronic/electrician workers. In addition the quality of the most of the studies reviewed is more than enough, so, the findings published can be considered quite reliable. Future epidemiological studies on ELF-EMF will be informative only if advancements will be made in reducing bias and/or if a better insight will be gained into the possible effect of bias on the results of these studies. In addition, in biological studies, the hypothesized mechanisms could be further explored.

Nowadays, the exposure to novel techniques, such as Bluetooth and Wi-Fi, has increased the use of EMF. The assessment of RF-EMF exposure is a challenge, because RF-EMF has various sources and is difficult to identify. Recent advancements in exposure measurement can contribute to an improved quality of studies in this field [50]. To gain a better insight into the proportion of population exposed, further nationwide surveys are needed.

Table 3. Incidence and mortality for other cancer localizations.

Authors	Localizations	Outcome	Epidemiologic Measures	Main Results	Quality of the study
Coggon et al. 1986	Larynx	incidence diagnosis	RR	0.5 not significant	8.5
Floderus et al. 1999	Larynx	incidence diagnosis	RR	Men Medium Exposure(MH) 1.3 (1.1-1.5); Men High Exposure(HE) 1.4 (1.2-1.6). Women MH 0.9 (0.5-1.7); Women HE 1.4 (0.8-2.2)	9
Vågerö et al. 1983	Larynx	incidence diagnosis	RR	1.46 (1.05-2.03)	8
Johansen et al. 1998	Larynx	incidence diagnosis	SIR	Men: 0.95 (0.7-1.3). Women: 0.90 (0.0-4.8)	9.5
Tynes et al. 1992	Larynx	incidence diagnosis	SIR	1.39 (1.08-1.76)	9
Vågerö et al. 1985	Larynx	incidence diagnosis	SMbR	1.4 (0.2-2.0)	6
Nichols et al. 2005	Larynx	mortality	SMR	Male 0.82 (0.58-1.13); Female 0	8
Vågerö et al. 1990	Ocular melanoma/eye tumour	incidence diagnosis	PRR (adj age) CI95%	1.18 (0.67-1.92) proportion risk in electical /electronic occupation compared to alla occupational groups combined.	9
Floderus et al. 1999	Ocular melanoma/eye tumour	incidence diagnosis	RR	Men Medium Exposure (MH) 1.1 (0.8-1.4); Men High Exposure (HE) 1.1 (0.9-1.5). Women MH 1,3 (0.8-2.1); Women HE 1,3 (0,8-2,0).	9
Nichols et al. 2005	Ocular melanoma/eye tumour	mortality	SMR	Male 46 (6-166); Female 0	8
Savitz et al. 1995	Ocular melanoma/eye tumour	mortality	SMR	0.55 (0.20-1.20)	9.5
Szmigielski et al. 1996	Oral cavity and pharynx	incidence diagnosis	OER (observed/expected ratio)	1.08 (0.82-1.24)	7.5
Degrave et al. 2008	Oral cavity and pharynx	mortality	ReR (Rate Ratio) CI95%	1.66 (0.23-12.19)	9
Floderus et al. 1999 *(continued)*	Oral cavity and pharynx	incidence diagnosis	RR	Men Medium Exposure (MH) 0.7 (0.6-0.8); Men High Exposure (HE) 0.7 (0.6-0.8). Women MH 1.4 (1.1-1.9); Women HE 1.0 (0.8-1.3).	9
Groves et al. 2002	Oral cavity and pharynx	mortality	RR	0.62 (0.35-1.0 8)	10
Vågerö et al. 1983	Oral cavity and pharynx	incidence diagnosis	RR	0.53 (0.31-0.89)	8

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Johansen et al. 1998	Oral cavity and pharynx	incidence diagnosis	SIR	Men: 0.91 (0.7-1.2) Women: 0.5 (0.1-1.9)	9.5
Tynes et al. 1992	Oral cavity and pharynx	incidence diagnosis	SIR	0.91 (0.76-1.09)	9
Vågerö et al. 1985	Oral cavity and pharynx	incidence diagnosis	SMbR	4.8 (0.6-17.4)	6
Vågerö et al. 1983	Pharynx	incidence diagnosis	RR	Mesopharynx = 2.30 (1.11-4.79)	8
Nichols et al. 2005	Pharynx	mortality	SMR	Male 0.61 (0.38-0.93); Female 0	8

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References

1. Milham S. Historical evidence that electrification caused the 20th century epidemic of "diseases of civilization. Med Hypotheses 2010;74(2):337-45.
2. Wertheimer N, Leeper E. Electrical wiring configurations and childhood cancer. Am J Epidemiol 1979;109:273-84.
3. Dolk H, Shaddick G, Walls P, Grundy C, Thakrar B, Kleinschmidt I, Elliott P. Cancer incidence near radio and television transmitters in Great Britain. I. Sutton Coldfield transmitter. Am J Epidemiol 1997;145(1):1-9.
4. Hocking B, Gordon IR, Grain HL, Hatfield GE. Cancer incidence and mortality and proximity to TV towers. Med J Aust. 1996 Dec 2-16;165(11-12):601-5. Erratum in: Med J Aust 1997; 166(2):80
5. IARC, (2002). Monographs on the evaluation of carcinogenic risks to humans. Volume 80: Non-ionizing radiation, part 1: Static and extremely low-frequency (ELF) electric and magnetic fields. p. 445.
6. WHO - World Health Organization. Extremely low frequency fields. Environmental Health Criteria, Vol. 238. Geneva, World Health Organization, 2007(http://www.who.int/pehemf/publications/facts/fs322_ELF_fields_italian.pdf. Ultimo accesso Gennaio 2012). IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Non-ionizing radiation, Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields. Lyon, IARC, 2002 (Monographs on the Evaluation of Carcinogenic Risks to Humans, 80. ICNIRP – International Commission on Non-Ionizing Radiation Protection. Exposure to static and low frequency electromagnetic fields, biological effects and health consequences (0-100 kHz). Bernhardt JH et al., eds. Oberschleissheim, International Commission on Non-ionizing Radiation Protection, 2003 (ICNIRP 13/2003).
7. Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 2009;6(6): e1000097.
8. Easterbrook PJ, Berlin JA, Gopalan R, Matthews DR. Publication bias in clinical research. The Lancet 1991; 337: 867-72.
9. La Torre G, Chiaradia G, Gianfagna F, De Laurentis A, Boccia S, Ricciardi W. Quality assessment in meta-analysis. Ital J Public Health 2006; 3:44-50.
10. Sahl JD, Kelsh MA, Greenland S. Cohort and nested case-control studies of hematopoietic cancers and brain cancer among electric utility workers. Epidemiology. 1993 Mar;4(2):104-14.
11. Guénel P, Raskmark P, Andersen JB, Lynge E.Incidence of cancer in persons with occupational exposure to electromagnetic fields in Denmark.Br J Ind Med. 1993;50(8):758-64.
12. Szmigielski S. Cancer morbidity in subjects occupationally exposed to high frequency (radiofrequency and microwave) electromagnetic radiation. Sci Total Environ. 1996;180(1):9-17.
13. Harrington JM, McBride DI, Sorahan T, Paddle GM, van Tongeren M. Occupational exposure to magnetic fields in relation to mortality from brain cancer among electricity generation and transmission workers. Occup Environ Med. 1997;54(1):7-13.
14. Milham S Jr. Mortality in Workers Exposed to Electromagnetic Fields. Environmental Health Perspectives 1985;62:297-300.
15. Degrave E, Meeusen B, Grivegnée AR, Boniol M, Autier P. Causes of death among Belgian professional military radar operators: a 37-year retrospective cohort study. Int J Cancer. 2009;124(4):945-51.
16. Floderus B, Stenlund C, Persson T. Occupational magnetic field exposure and site-specific cancer incidence: a Swedish cohort study . Cancer Causes and Control 1999; 10: 323-32.
17. Håkansson N, Floderus B, Gustavsson P, Johansen C, Olsen JH. Cancer incidence and magnetic field exposure

in industries using resistance welding in Sweden. Occup Environ Med. 2002;59(7):481-6.
18. Juutilainen J, Läärä E, Pukkala E. Incidence of leukaemia and brain tumours in Finnish workers exposed to ELF magnetic fields. Int Arch Occup Environ Health 1990;62(4):289-93.
19. Sorahan T, Nichols L, van Tongeren M, Harrington JM. Occupational exposure to magnetic fields relative to mortality from brain tumours: updated and revised findings from a study of United Kingdom electricity generation and transmission workers, 1973-97. Occup Environ Med. 2001; 58(10):626-30.
20. Johansen C, Olsen JH. Risk of cancer among Danish utility workers--a nationwide cohort study. Am J Epidemiol 1998;147(6):548-55.
21. Johansen C, Raaschou Nielsen O, Olsen JH, Schüz J. Risk for leukaemia and brain and breast cancer among Danish utility workers: a second follow-up. Occup Environ Med. 2007;64(11):782-4
22. Baris D, Armstrong BG, Deadman J, Thériault G. A mortality study of electrical utility workers in Québec. Occup Environ Med. 1996;53(1):25-31.
23. Kelsh MA, Sahl JD. Mortality among a cohort of electric utility workers, 1960-1991. Am J Ind Med. 1997 May;31(5):534-44.
24. Nichols L, Sorahan T. Mortality of UK electricity generation and transmission workers, 1973-2002.Occup Med (Lond). 2005;55(7):541-8.
25. Röösli M, Lörtscher M, Egger M, Pfluger D, Schreier N, Lörtscher E, Locher P, Spoerri A, Minder C. Leukaemia, brain tumours and exposure to extremely low frequency magnetic fields: cohort study of Swiss railway employees. Occup Environ Med. 2007;64(8):553-9.
26. Savitz DA, Loomis DP. Magnetic field exposure in relation to leukemia and brain cancer mortality among electric utility workers. Am J Epidemiol 1995;141(2):123-34.
27. Tynes T, Andersen A, Langmark F. Incidence of cancer in Norwegian workers potentially exposed to electromagnetic fields. Am J Epidemiol 1992;136(1):81-8.
28. Tynes T, Reitan JB, Andersen A. Incidence of cancer among workers in Norwegian hydroelectric companies. Scand J Work Environ Health 1994;20(5):339-44.
29. Andersen A, Langmark F. Incidence of cancer in Norwegian workers potentially exposed to electromagnetic fields. Am J Epidemiol 1992;136(1):81-8).
30. Tynes T, Hannevik M, Andersen A, Vistnes AI, Haldorsen T. Incidence of breast cancer in Norwegian female radio and telegraph operators. Cancer Causes Control 1996;7(2):197-204.
31. McLaughlin JK, Malker HS, Blot WJ, Malker BK, Stone BJ, Weiner JA, Ericsson JL, Fraumeni JF Jr. Occupational risks for intracranial glioma in Sweden. J Natl Cancer Inst 1987;78(2):253-7.
32. Olin R, Vågerö D, Ahlbom A. Mortality experience of electrical engineers. Br J Ind Med 1985;42(3):211-2.
33. Coggon D, Pannett B, Osmond C, Acheson ED. A survey of cancer and occupation in young and middle aged men. II. Non-respiratory cancers. Br J Ind Med. 1986;43(6):381-6.
34. Groves FD, Page WF, Gridley G, Lisimaque L, Stewart PA, Tarone RE, Gail MH, Boice JD Jr, Beebe GW. Cancer in Korean war navy technicians: mortality survey after 40 years. Am J Epidemiol 2002;155(9):810-8.
35. Morgan RW, Kelsh MA, Zhao K, Exuzides KA, Heringer S, Negrete W. Radiofrequency exposure and mortality from cancer of the brain and lymphatic/hematopoietic systems. Epidemiology 2000;11(2):118-27 .
36. Vågerö D, Olin R. Incidence of cancer in the electronics industry: using the new Swedish Cancer Environment Registry as a screening instrument. Br J Ind Med. 1983 May;40(2):188-92.
37. Vågerö D, Ahlbom A, Olin R, Sahlsten S. Cancer morbidity among workers in the telecommunications industry. Br J Ind Med. 1985;42(3):191-5.
38. Vågerö D, Swerdlow AJ, Beral V. Occupation and malignant melanoma: a study based on cancer registration data in England and Wales and in Sweden. Br J Ind Med 1990; 47(5):317-24.
39. Boffetta P. Human cancer from environmental pollutants: the epidemiological evidence. Mutat Res. 2006;608(2):157-62.
40. Elwood JM. A critical review of epidemiologic studies of radiofrequency exposure and human cancers. Environ Health Perspect 1999;107 Suppl 1:155-68.
41. Savitz DA. Epidemiologic studies of electric and magnetic fields and cancer: strategies for extending knowledge. Environ Health Perspect 1993;101 Suppl 4:83-91.
42. Coleman M, Beral V. A review of epidemiological studies of the health effects ofliving near or working with electricity generation and transmission equipment. Int J Epidemiol 1988;17:1-13.
43. Savitz DA, Calle EE. Leukemia and occupational exposure to electromagnetic fields: review of epidemiological surveys. J Occup Med 1987;29:47-51.
44. Lin RS, Dischinger PC, Conde J, Farrell KP. Occupational exposure to electromagnetic fields and the occurrence of brain tumors. J Occup Med 1985;27:413-419.
45. Loomis DP, Savitz DA, Ananth CV. Breast cancer

mortality among female electrical workers in the United States.J Natl Cancer Inst 1994;86(12):921-5.
46. Matanoski GM, Breysse PN, Elliott EA. Electromagnetic field exposure and male breast cancer. Lancet 1991;337(8743):737.
47. Demers PA, Thomas DB, Rosenblatt KA, Jimenez LM, McTiernan A, Stalsberg H, Stemhagen A, Thompson WD, Curnen MG, Satariano W, Austin DF, Isacson P, Greenberg RS, Key C, Kolonel LN, West DW. Occupational exposure to electromagnetic fields and breast cancer in men. Am J Epidemiol 1991;134(4):340-7.
48. Floderus B, Persson T, Stenlund C, Wennberg A, Ost A, Knave B. Occupational exposure to electromagnetic fields in relation to leukemia and brain tumors: a case-control study in Sweden. Cancer Causes Control 1993;4(5):465-76.
49. Thériault G, Goldberg M, Miller AB, Armstrong B, Guénel P, Deadman J, Imbernon E, To T, Chevalier A, Cyr D, et al. Cancer risks associated with occupational exposure to magnetic fields among electric utility workers in Ontario and Quebec, Canada, and France: 1970-1989. Am J Epidemiol 1994;139(6):550-72.
50. Frei P, Mohler E, Neubauer G, Theis G, Burgi A, Frohlich J, Braun-Fahrlander C, Bolte J, Egger M, Röösli M. Temporal and spatial variability of personal exposure to radio frequency electromagnetic fields. Environ Res 2009;109:779–85.