Evidence for a health risk by RF on humans living around mobile phone base stations: From radiofrequency sickness to cancer

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Evidence for a health risk by RF on humans living around mobile phone base stations: from radiofrequency sickness to cancer

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Abstract
The objective of this work was to perform a complete review of the existing scientific literature to update the knowledge on the effects of base station antennas on humans. Studies performed in real urban conditions, with mobile phone base stations situated close to apartments, were selected. Overall results of this review show three types of effects by base station antennas on the health of people: radiofrequency sickness (RS), cancer (C) and changes in biochemical parameters (CBP). Considering all the studies reviewed globally (n=38), 73.6% (28/38) showed effects: 73.9% (17/23) for radiofrequency sickness, 76.9% (10/13) for cancer and 75.0% (6/8) for changes in biochemical parameters. Furthermore, studies that did not meet the strict conditions to be included in this review provided important supplementary evidence. The existence of similar effects from studies by different sources (but with RF of similar characteristics), such as radar, radio and television antennas, wireless smart meters and laboratory studies, reinforce the conclusions of this review. Of special importance are the studies performed on animals or trees near base station antennas that cannot be aware of their proximity and to which psychosomatic effects can never be attributed.

Key words
Base station, cell tower, health, mast, RF radiation, microwave syndrome, radar, radio antennas.

Short title: Health risk by mobile phone base stations
Introduction
During the last few decades, hundreds of thousands of mobile phone base stations and other types of wireless communications antennas have been installed around the world, in cities and in nature, including protected natural areas, in addition to pre-existing antennas (television, radio broadcasting, radar, etc.). Only the aesthetic aspects or urban regulations have been generally considered in this deployment, while the biological, environmental and health impacts of the associated non-ionizing electromagnetic radiation emissions have not been assessed so far. Therefore, the effects on humans living around these anthropogenic electromagnetic field sources (antennas) have not been considered.

In France, there is a significant contribution of mobile phone base stations in the exposure to radiofrequency electromagnetic fields (RF-EMF) of urban citizens living nearby (De Giuduci et al., 2021). Some studies from India indicate that more than 15% of people have levels of EMF strength above 12 V/m due to their proximity to antennas (Premial and Eldhose, 2017). Exposure estimates have shown that RF-EMF from mobile telephone systems is stronger in urban than in rural areas. For instance, in Sweden the levels of RF radiation have increased considerably in recent years, both outdoor and indoor, due to new telecommunication technologies, and the median power density measured for RF fields between 30 MHz and 3 GHz was 16 µW/m² in rural areas, 270 µW/m² in urban areas and 2400 µW/m² in city areas (Hardell et al., 2018). Total exposure varies not only between urban and rural areas but also, depending on residential characteristics, between different floors of a building, with a tendency for building exposure to increase at higher floors (Breckenkamp et al., 2012).

Over the past five decades, and more intensively since the beginning of this century, many studies and several reviews have been published on the effects of anthropogenic electromagnetic radiation on humans living around the antennas. The first studies were carried out with radio and television antennas, investigating increases in cancer and leukaemia (Milham 1988; Maskarinec et al., 1994; Hocking et al., 1996; Dolk et al., 1997a,b; Michelozzi et al., 1998; Altpeter et al., 2000), as well as around radars (Kolodyski and Kolodynska, 1996; Goldsmith, 1997).

Regarding base station antennas, there are scientific discrepancies in their effects: some studies concluded that there are no health-related effects (e.g. Augner and Hacker, 2009; Blettner et al., 2009; Röösli et al., 2010; Baliatsas et al., 2016) whereas others found increases in cancer and other health problems in humans living around antennas (e.g. Santini et al., 2002; Navarro et al., 2003; Bortkiewicz et al., 2004; Eger et al., 2004; Wolf and Wolf, 2004; Abdel-Rassoul et al., 2007; Khurana et al., 2010; Dode et al., 2011; Shinjyo and Shinjyo, 2014; Gandhi et al., 2015; López et al., 2021; Rodrigues et al., 2021). There is a specific symptomatology linked to radar and RF exposure at low levels, characterized by functional disturbances of the central nervous system (headache, sleep disturbance, discomfort, irritability, depression, memory loss, dizziness, fatigue, nausea, appetite loss, difficulty in concentration, dizziness, etc.), that has been termed ‘RF sickness’ (Lilienfeld, 1978; Johnson Liakouris, 1998; Navarro et al., 2003).

The objective of this study was to perform a complete review of the existing scientific literature to update the knowledge on the effects of base stations on humans living around the antennas.
Methods

A search was performed in the EMF portal, Google Scholar and PubMed databases with the words: “mobile phone base station and health” or “cell tower and health”.

Only studies performed in real urban conditions, with mobile phone base stations situated close to apartments, were selected. Studies conducted in larger regions with numerous antennas, based on surveys and geographic data, were also included.

On the contrary, studies were excluded that considered different sources of electromagnetic radiation, such as mobile phone base stations together with broadcast transmitters (TV and radio), radar, mobile phones, cordless phones, Wi-Fi or wireless smart meters. Also excluded were those that included antennas and powerlines jointly. Studies that only performed measurements or modelling of radiation levels in the environment of the antennas or in the body, but did not deal with health effects, were excluded, as were surveys on risk perception and the nocebo effect, modelled radiofrequency electromagnetic field exposure from mobile- phone base stations or perceived exposure. All experimental laboratory studies, experiments in an exposure chamber or adapted room were also excluded. Finally, the comments or criticism of previously published studies were also excluded. However, due to their importance the conclusions of some of the excluded studies will be discussed in the corresponding section.

Results

The studies that met the selected criteria are presented in chronological order in Table 1, catalogued as Y/N depending on whether or not they found effects. The selected studies cover three types of effects: radiofrequency sickness (RS) (according to Lilienfeld et al., 1978; Johnson Liakouris, 1998), cancer (C) and changes in biochemical parameters (CBP). Table 1 also includes the authors, year and country, antenna type, study design, diseases and symptoms found/not found and the main conclusions of each study.

Table 1: Studies that met the selected criteria

<table>
<thead>
<tr>
<th>№</th>
<th>Reference and country</th>
<th>Antenna type</th>
<th>Study design</th>
<th>Diseases and symptoms found/not found</th>
<th>Main conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Santini et al., 2002 and 2003 a and b</td>
<td>Base station antennas GSM 900 and 1800 MHz</td>
<td>Questionnaire survey in 530 people</td>
<td>Effects found on: -tiredness -headache -sleep disturbance -discomfort -irritability -depression -memory loss -dizziness -libido decrease -visual perturbations</td>
<td>Effects occur up to a distance of 300 meters from the antenna. Older subjects are more sensitive. Also, that the facing location is the worst position for some symptoms studied, especially for distances till 100m from base stations. The frequency of reported complaints is significantly higher for women in comparison with men</td>
</tr>
<tr>
<td>2</td>
<td>Gómez-Perretta et al., 2013</td>
<td>Base station antennas GSM 900 and 1800 MHz</td>
<td>Questionnaire survey in 101 people and electric field measurements</td>
<td>Effects found on: -fatigue -irritability -headache -nausea -appetite loss -discomfort -sleep disturbance -depression</td>
<td>Significant correlation between the declared severity of the symptoms and the measured power density. The separation of respondents into two different exposure groups also showed an increase of the declared severity in the group with the higher exposure. The incidence of most of the symptoms was related to exposure levels, independently of</td>
</tr>
<tr>
<td>No.</td>
<td>Authors, Year, Location</td>
<td>Type of Antennas</td>
<td>Method</td>
<td>Findings</td>
<td>Main Findings</td>
</tr>
<tr>
<td>-----</td>
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</tr>
<tr>
<td>3 YRS</td>
<td>Bortkiewicz et al., 2004 Poland</td>
<td>Base station antennas</td>
<td>Review of previous publications</td>
<td>Effects found on: -circulatory system -sleep disturbances -irritability depression -blurred vision -concentration -difficulties nausea -lack of appetite -headache -vertigo</td>
<td>Relationship between the incidence of individual symptoms, the level of exposure, and the distance. This association was observed in both groups of persons, those who linked their complaints with the presence of the base station and those who did not notice such a relation.</td>
</tr>
<tr>
<td>4 YRS</td>
<td>Eger et al., 2004 Germany</td>
<td>2 Base station antennas</td>
<td>Number of cancer cases in the selected population (1,045 resident) in Naila to compare results an inner area (within a distance of 400 metres from the base station antennas) and outer area (beyond 400 metres).</td>
<td>The number of newly developed cancer cases in the inner area is more than the expected number taken from the cancer register, which represents the total population being irradiated. The group who had lived during the past five years within a distance of 400 m from the Base station antennas have a two times higher risk of developing cancer than that of the average population. The relative risk of getting cancer in the inner area compared with the Saarland cancer register is 1.7.</td>
<td>The risk of newly developing cancer was three times higher among those patients who had lived during past ten years (1994-2004), within a distance of 400 m. from the cellular transmitter, in comparison to those who had lived further away.</td>
</tr>
<tr>
<td>5 YRS</td>
<td>Wolf and Wolf, 2004 Israel</td>
<td>1 Base station antenna</td>
<td>A cancer incidence study to investigate the incidence of cancer cases of individuals (the cohort included 622 people) exposed to a Base station antenna, in comparison to those of a nearby clinic out of that area, to the national incidence rates of the whole country and to the incidence rates in the whole town of Netanya.</td>
<td>There were 4.13 times more cases of cancer in area A (breast carcinoma, ovary carcinoma, lung carcinoma, Hodgkin’s disease, osteoid osteoma, and hypernephroma) than in the entire population.</td>
<td>The study indicates an association between an increased incidence of cancer and living in proximity to a Base station antenna.</td>
</tr>
<tr>
<td>6 YRS</td>
<td>Hutter et al., 2006 Austria</td>
<td>10 Base station antennas in the 900 MHz band</td>
<td>Questionnaire survey in 365 subjects and exposure measurements</td>
<td>Effects found on: -headache -difficulties to concentrate -cold hands or feet No effects found on: -vertigo -palpitations -tremor -hot flushes -sweating -loss of appetite -loss of energy, -exhaustion -tiredness -feeling strained -sleep</td>
<td>Self-reported symptoms like headache and difficulties in concentrating show an association with microwave exposure from base stations, not attributable to subjects’ fear of health effects from these sources. Other symptoms, like sleeping problems, seem to be more due to fear of adverse health effects than actual exposure.</td>
</tr>
<tr>
<td>7 YRS</td>
<td>Abdel-Rassoul et al., 2007 Egypt</td>
<td>Base station antennas (GSM)</td>
<td>Questionnaire survey on 85 exposed persons and 80 controls</td>
<td>Effects found on: -headache -memory changes -dizziness -tremors -depressive symptoms</td>
<td>The prevalence of neuropsychiatric complaints were significantly higher among exposed inhabitants than controls. Inhabitants living nearby mobile phone base stations are at risk for developing neuropsychiatric problems and some</td>
</tr>
<tr>
<td>Study Number</td>
<td>Author(s)</td>
<td>Year</td>
<td>Country</td>
<td>Study Design</td>
<td>Objective</td>
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<tr>
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</tr>
<tr>
<td>8</td>
<td>Augner and Hacker, 2009</td>
<td>Austria</td>
<td>Base station antennas</td>
<td>Questionnaire survey on fifty-seven participants and saliva samples</td>
<td>Self-declared base station neighbors (≤ 100 meters) had significantly higher concentrations of alpha-amylase in their saliva, higher rates in symptoms, somatization, obsessive-compulsive, anxiety, phobic anxiety. There were no differences in EMF-related health concern scales.</td>
</tr>
<tr>
<td>9</td>
<td>Blettner et al., 2009</td>
<td>Germany</td>
<td>Base station antennas (GMS 900 and 1800 and UMTS 2170)</td>
<td>Questionnaire survey on 30047 participants and geo-coding information on the residence distance (less or more than 500 m) to the nearest mobile phone base station. In a second phase RF measurements were conducted for a subsample in the households of 1500 persons</td>
<td>The mailed questionnaire included a list of 38 symptoms that have been reported in previous studies to be possibly associated with RF-EMF exposure.</td>
</tr>
<tr>
<td>10</td>
<td>Kundi and Hutter, 2009</td>
<td>Austria</td>
<td>Base station antennas</td>
<td>Review of previous publications</td>
<td>Effects found on: Adverse neurobehavioral symptoms or cancer</td>
</tr>
<tr>
<td>11</td>
<td>Eger and Jahn, 2010</td>
<td>Germany</td>
<td>Base station antennas</td>
<td>Questionnaire survey on 255 persons</td>
<td>Effects found on: -sleep disturbance -No effects found on: -Blurred vision -Irritability -Lack of concentration</td>
</tr>
</tbody>
</table>
| No effects found on:  
| - toothaches  
| - hormonal imbalances  
| - weight gain  
| - weight loss |

| 12 | Elliott et al., 2010  
| Great Britain  
| Base station antennas  
| Data on all registered cases of cancer in children aged 0-4 in Great Britain and data on mobile phone base stations to investigate the risk of early childhood cancer associated with the mother’s exposure to radiofrequency from and proximity to mobile phone base stations during pregnancy.  
| Of the 1397 cases, there were 251 brain and central nervous system cancers and 527 cases of leukaemia and non-Hodgkin’s lymphoma. The study found no association between mobile phone base stations and risk of cancer.  
| In this systematic national investigation the authors found no association between risk of cancer in young children and estimated exposures to radiofrequency from mobile phone base stations during pregnancy. However there is a research paper limitation on page 5: "our models did not include information on other sources of radiofrequency exposure, such as from microwells or picocells" and the city centers (especially) are full of these kind of antennas. |

| 13 | Khurana et al., 2010  
| international  
| Base station antennas  
| Review of previous publications  
| Effects found on:  
| - Adverse neurobehavioral symptoms or cancer  
| The authors identified a total of 10 epidemiological studies that assessed for putative health effects of mobile base stations. Seven of these studies explored the association between base station proximity and neurobehavioral effects and three investigated cancer. The authors found that eight of the 10 studies reported increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at distances < 500 meters from base stations. |

| 14 | Röösli et al., 2010  
| Switzerland  
| Base station antennas  
| (GMS 900 and 1800 and UMTS 2170)  
| Systematic review  
| There are no adverse effects  
| Not indication of an association between any health outcome and RF-EMF exposure from mobile phone base stations at levels typically found in our everyday environment. There is also no evidence that EHS individuals are more susceptible to base station radiation than the rest of the population. The evidence for the absence of long-term effects is limited. |

| 15 | Yildirim et al., 2010  
| Turkey  
| Base station antennas  
| Blood samples to analyse the micronucleus (MN) frequency and chromosomal aberrations on blood in people living around mobile phone base stations and healthy controls.  
| There was not a significant difference of MN frequency and chromosomal aberrations between the two study groups.  
| Mobile phones and their base stations do not produce important carcinogenic changes. |

| 16 | Alazawi., 2011  
| Iran  
| 8 Base station antennas  
| Questionnaire survey on 375 subjects. Not measurements  
| Effects found on:  
| - headaches  
| - sleep disturbances  
| - irritability  
| - depressive  
| - tendencies  
| - feeling of discomfort,  
| - difficulties in concentration  
| - memory loss  
| - lowering of libido  
| This study shows that inhabitants living nearby mobile phone base stations are at risk for developing non specific health symptoms, the facing position appears to be the worst one for distances from cellular phone base stations < 100 m. It is advisable that cellular phone base stations should not be sited closer than 300 m to populations, as a precautionary measure, sitting of base stations should be such as to minimize exposure of neighbors. |

| 17 | Dode et al., 2011  
| Brazil  
| Base station antennas  
| This research was conducted in a broad environmental context, aiming to verify if there is a spatial correlation between the Base station antennas and the cases of death by neoplasia during the period between 1996 and 2006 in Belo Horizonte municipality from 1996 to 2006.  
| The mortality rates and the relative risk were higher for the residents inside a radius of 500 m from the Base station antennas, compared to the average mortality rate of the entire city, and a decreased dose-response gradient was observed for residents who lived farther.  
<p>| The research showed the existence of a spatial correlation between cases of death by neoplasia and the locations of the Base station antennas, in the Belo Horizonte municipality from 1996 to 2006. |</p>
<table>
<thead>
<tr>
<th>No.</th>
<th>Authors and Year</th>
<th>Country</th>
<th>Type of Study</th>
<th>Results Summary</th>
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</thead>
<tbody>
<tr>
<td>18</td>
<td>Li et al., 2012</td>
<td>Taiwan</td>
<td>Base station antennas</td>
<td>Taiwanese children with higher-than-median exposure of RF potentially emitted from Base station antennas were at significantly increased risk of all neoplasms combined. Although there were also positive associations between RF power density and risks of brain neoplasm and leukemia in children, such associations did not reach statistical significance.</td>
</tr>
<tr>
<td>19</td>
<td>Stewart et al., 2012</td>
<td>Great Britain</td>
<td>1 Base station antennas (GMS 1800)</td>
<td>Data on cancer incidence and mortality assessing the medical information of near residents. The study cannot conclude that the base station is responsible for the incidence of cancer in the local residents. Although the age range for local residents with cancer in the suspected cluster was younger than might be generally expected, there was no evidence that their cancer incidence is associated with the mobile phone base station. 10 cancers were registered after installation of the base station. However, the collection of cancers does not fulfill the criteria for a cancer cluster; the cases are a mixed variety of relatively common cancers. No single type of cancer was dominant, all but one were common types of cancer and none were seen in a group not usually affected by that cancer. Data from primary and secondary care also provide evidence that lifestyle and family history factors could have contributed to some individual cases.</td>
</tr>
<tr>
<td>20</td>
<td>Islam and Mohammed, 2014</td>
<td>Bangladesh</td>
<td>Base station antennas</td>
<td>Questionnaire survey on 220 adults living near a Base station antenna for at least one year in two selected areas. Half of the respondents experienced problems in sleeping patterns, recent episodes of headache or dizziness and mood change, anxiety, or depression. 11 respondents experienced some generalized burning sensation and 4 reported episodes of shaking or fits. 48 respondents mentioned one or more other health effects, such as mood changes/problem, buzzing in the head, hopelessness, palpitation, tachycardia, heaviness of chest, anorexia, diarrhoea, and skin diseases. From the results of the study cannot conclude that the health effects are direct results of the base station antennas. However, the complaints were similar to those of other studies, which shows the importance of conducting further research to determine the effects of electromagnetic radiation from base station antennas on human health and should be considered as a public health concern.</td>
</tr>
<tr>
<td>21</td>
<td>Pachuau and Pachuau, 2014</td>
<td>India</td>
<td>Base station antennas (GSM 900)</td>
<td>Questionnaire survey conducted on 64 adults (31 female, 33 male) and electric field measurements. Health symptoms of RF exposure faced by the inhabitants within 50m and outside 50m from the tower were analysed and compared. Effects found on: <em>Muscle pain</em> <em>Fatigue</em> <em>Sleep disorder</em> <em>Nausea</em> <em>Skin problem</em> <em>Dizziness</em> <em>Feeling of discomfort</em> <em>Difficulty in concentration</em> <em>Memory loss</em> <em>Visual disruption</em> Inhabitants living within 50m had more health complaints than those living outside 50m. It was also found that females had more complaints than males.</td>
</tr>
<tr>
<td>22</td>
<td>Shinjyo and Shinjyo, 2014</td>
<td>Japan</td>
<td>2 base station antennas (CDMA 800 MHz and 2 GHz)</td>
<td>Medical examinations and health questionnaires comparing the health of 107 residents during the Effects found on: <em>Fatigue</em> <em>Eye problems</em> <em>Sleep disturbances</em> <em>Dizziness</em> <em>Headache</em> A total of 34 residents suffered from health problems after installation of the 800 MHz antennas. Three months after their removal this number decreased to 13. There were 41 residents who had health problems after installation of the 2 GHz antennas, and this...</td>
</tr>
<tr>
<td>Study No.</td>
<td>Authors</td>
<td>Country</td>
<td>Exposure Details</td>
<td>Questionnaire/Measurements</td>
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<tr>
<td>23</td>
<td>Gandhi et al., 2015</td>
<td>India</td>
<td>Base station antennas</td>
<td>Questionnaire survey and blood samples from 91 individuals, with 70% (63) residing in a populated area with a mobile phone base station (the sample group) and 30% (28) in a sparsely-populated zone without any nearby base stations (the control group); Radiofrequency field measurements</td>
</tr>
<tr>
<td>24</td>
<td>Meo et al., 2015</td>
<td>Saudi Arabia</td>
<td>2 Base station antennas (925 MHz) near two schools</td>
<td>RF-EMF measurements and blood sample collection</td>
</tr>
<tr>
<td>25</td>
<td>Pachuau et al., 2015</td>
<td>India</td>
<td>Base station antennas (GSM 900)</td>
<td>Questionnaire survey from 50 exposed and 50 control individuals; Power density measurements</td>
</tr>
<tr>
<td>26</td>
<td>Al-Quzwi et al., 2016</td>
<td>Iraq</td>
<td>Base station antennas</td>
<td>Questionnaire survey. Two hundred couples (one hundred subfertile couples as a study group, and one hundred fertile couples as a control group. semen analysis</td>
</tr>
<tr>
<td>27</td>
<td>Baliatsas et al., 2016</td>
<td>The Netherlands</td>
<td>Base station antennas (GSM and UMTS)</td>
<td>Health records from 1069 adult participants, All participants were living within 500 m from the nearest base station. A propagation model combined with a questionnaire was used</td>
</tr>
<tr>
<td>N</td>
<td>Authors</td>
<td>Country</td>
<td>No. of Base Station Antennas</td>
<td>Methodology</td>
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<tr>
<td>28</td>
<td>Klaps et al., 2016</td>
<td>Austria</td>
<td>Base station antennas</td>
<td>Meta-analysis based on the results of 17 studies</td>
</tr>
<tr>
<td>29</td>
<td>Singh et al., 2016</td>
<td>India</td>
<td>4 Base station antennas</td>
<td>Questionnaire survey and salivary analysis in 20 individuals (case group) and 20 (control group)</td>
</tr>
<tr>
<td>30</td>
<td>Premial and Eldhose, 2017</td>
<td>India</td>
<td>14 Base station antennas</td>
<td>Questionnaire survey (229 persons) and power density measurements</td>
</tr>
<tr>
<td>31</td>
<td>Taheri et al., 2017</td>
<td>Iran</td>
<td>Base station antennas</td>
<td>45 healthy individuals with their home near BTS antenna (exposed group) and 45 healthy subjects who were away from the antenna</td>
</tr>
<tr>
<td>32</td>
<td>Vijay and Choudhary, 2017</td>
<td>India</td>
<td>40 Base station antennas (900 - 1800 MHz)</td>
<td>Questionnaire survey</td>
</tr>
<tr>
<td>33</td>
<td>Zothansiama et al., 2017</td>
<td>India</td>
<td>6 Base station antennas (900 - 1800 MHz)</td>
<td>Questionnaire survey. Blood sample collection and lymphocyte culture.</td>
</tr>
<tr>
<td>Country</td>
<td>Study Year</td>
<td>Study Details</td>
<td>Methodology</td>
<td>Key Findings</td>
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<tr>
<td>Brazil</td>
<td>2021</td>
<td>Rodrigues et al.</td>
<td>Base station antennas</td>
<td>This is an ecological study using capitals as the unit of analysis. The authors collected information on the</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>2019</td>
<td>Meo et al.</td>
<td>Two different schools both situated nearby base station antennas (925 MHz)</td>
<td>CBP Power density measurement. Exposed group (n = 40) Control group (n=40) The study was envisaged to evaluate the effect of RFR on the DNA damage and antioxidant status in cultured human peripheral blood lymphocytes of individuals residing in the vicinity of mobile phone base stations and comparing it with healthy controls.</td>
</tr>
<tr>
<td>Iraq</td>
<td>2021</td>
<td>Ali et al.</td>
<td>Base station antennas (900-1800 MHz.)</td>
<td>CBP Two different schools both situated nearby base station antennas (925 MHz) Cognitive function, motor screening task and spatial working memory were tested, and also RF measurements were made.</td>
</tr>
<tr>
<td>Spain</td>
<td>2021</td>
<td>López et al.</td>
<td>Questionnaire survey on 268 persons, 174 in exposed area and 94 in control area, and EMF measurements</td>
<td>CBP 9 Base station antennas Questionnaire survey on 268 persons, 174 in exposed area and 94 in control area, and EMF measurements</td>
</tr>
<tr>
<td>France</td>
<td>2021</td>
<td>Martin et al.</td>
<td>Base station antennas</td>
<td>CBP 354 residents from buildings located at a distance of 250 m or less from the base station antennas in the main transmit beam of the antennas and home exposure measurements</td>
</tr>
<tr>
<td>Total Spanish population</td>
<td>2021</td>
<td>López et al.</td>
<td>Questionnaire survey on 268 persons, 174 in exposed area and 94 in control area, and EMF measurements</td>
<td>CBP 9 Base station antennas Questionnaire survey on 268 persons, 174 in exposed area and 94 in control area, and EMF measurements</td>
</tr>
</tbody>
</table>

The findings of the study do not support the hypothesis of an association between RF-EMF exposure and health outcomes, such as self-reported non-specific or insomnia-like symptoms in the general population. However, they may suggest a possible association between such exposure and insomnia-like symptoms among people reporting environmental concerns. The results indicates that the exposure to radiofrequency electromagnetic fields from an RBS increases the rate of mortality by all cancers and specifically by breast, cervix, lung, and esophageal cancers. These
number of deaths by cancer, gender, age group, gross domestic product per capita, death year, and the amount of exposure over a lifetime and investigated all cancer types and some specific types (breast, cervix, lung, and esophagus cancers).

Radiofrequency, the higher the median of mortality rate.

Conclusions are based on the fact that the findings of the study indicate that, the higher the RBS radiofrequency exposure, the higher the cancer mortality rate, especially for cervix cancer. The spatial analysis showed that the highest radiofrequency exposure was observed in a city located in the southern region of Brazil, which also showed the highest mortality rate for all types of cancer and specifically for lung and breast cancers.

Considering all the selected studies (n=38), 73.6% (28/38) showed effects: 73.9% (17/23) for radiofrequency sickness, 76.9% (10/13) for cancer and 75.0% (6/8) for changes in biochemical parameters (Figure 1). Therefore, most of the studies carried by research groups from twenty different countries reach the same conclusions.

For the reasons previously explained, the following studies (n=85) were not considered in this review, even though the conclusions of some of these studies will be discussed later due to their importance regarding the similarities of the electromagnetic radiation types involved and the effects found in many cases. Several studies only performed measurements or modelling of radiation levels in the environment of the antennas or in the body, but did not deal with the effects on health (e.g. Aniołczyk, 1999; Henderson et al., 2006; Keow et al., 2006; Neitzke et al., 2007; Burgi et al., 2008; Augner et al., 2009; Chen and Chuang, 2009; Schmiedel et al., 2009; Viel et al., 2009; Hansson et al., 2011; Alhekail et al., 2012; Breckenkamp et al., 2012; Beekhuizen et al., 2013; Bürgi et al., 2014; Iyare et al., 2014; Urbinello et al., 2014; Lemaire et al., 2016; Admawi, 2021; De Giudici et al., 2021; Kazaure et al., 2021; Yetiş and Kayili, 2021). Some were surveys on risk perception and the nocebo effect, modelled RF-EMF exposure from mobile-phone base stations or perceived exposure (Wiedemann et al., 2006; Dohle et al., 2012; Kowall et al., 2012; Freudenstein et al., 2015; Dieudonné, 2016; Klaps et al., 2016; Martens et al., 2017; Koh et al., 2020). Others jointly considered various sources of electromagnetic fields such as telephone antennas, mobile phones, cordless phones, Wi-Fi, powerlines or wireless smart meters (Seitz et al., 2005; Bialiatsas et al., 2011; Atzmon et al., 2012; Eskander et al., 2012; Frei et al., 2012; Lamech, 2014; Singh and Pati, 2016; Boehmert et al., 2020; Akkam et al., 2020). Some studied the effects of radio or television antennas (Milham 1988; Maskarinec et al., 1994; Hocking et al., 1996; Dolk et al., 1997 a and b; McKenzie et al., 1998; Michelozzi et al., 1998; Altpeter et al., 2000; Hocking and Gordon, 2000; Boscolo et al., 2001; Cooper et al., 2001; Michelozzi et al., 2002; Hallberg and Johansson, 2002; Elwood, 2003; Ha et al., 2003; Park et al., 2004; Abelín et al., 2005; Altpeter et al., 2006; Ha et al., 2007; Satta et al., 2018). Others were radar studies (Kolodynski and Kolodynska, 1996; Goldsmith, 1997; Szmigielski et al., 2001; Yakymenko et al., 2011; Schoeni et al., 2016; Martens et al., 2018). Some studies performed experiments in a laboratory, exposure chamber or adapted room, with simulated or real electromagnetic radiation from base station antennas (e.g. Zwamborn et al., 2003; Hinrichs et al., 2005; Regel et al., 2006 and 2007; Eiltiti et al., 2007; Leitgeb et al., 2008; Riddervold et al., 2008; Augner et al., 2009; Augner et al, 2010; Wallace et al., 2010; Danker-Hopfe et al., 2010; Falcioni et al., 2018; Azimzadehand Jelodar, 2019; Smith-Roe et al. 2020). Some reports were comments or criticisms of previously published studies (e.g. Coggon, 2006; Röösi and Huss, 2008; Bithell, 2010; Dode and Leão, 2012; Foster and Trottier, 2012; Mortazavi, 2014 and 2017).
Discussion

The results of this review show three types of effects by base station antennas on the health of humans: radiofrequency sickness, cancer and changes in biochemical parameters (Figure 1). From among all these studies, most of them found effects (73.6%). Thus, despite some limitations and differences in study design, statistical measures, risk estimates and exposure categories (Khurana et al., 2010), together they provide a consistent view of the effects on the health of people living in the vicinity of base station antennas.

Studies conducted in large regions with numerous antennas, based on surveys and geographic data (e.g. Augner and Hacker, 2009; Dode et al., 2011; Baliatsas et al., 2016; Martens et al., 2017; Dode et al. et al., 2021), have the limitation that there may be many factors other than the base station antennas affecting the health of the population (environmental and occupational determinants of diseases and symptoms, individual characteristics such as food and life habits, activity level, smoking, self-medication, individual pathologies or genetic factors) that can act as confounding factors. It is important to mention here that the meters used for power density measurements in research papers should have more high quality equipment and better measurement methods.

On the other hand, some studies did not meet the strict conditions to be considered in this review, but due to their importance regarding the similarities of the electromagnetic radiation types involved and the effects found in many cases, they provide important supplementary evidence, as we will see in the next paragraphs.

For example, mobile phone users had an increased risk of headache (one of the typical symptoms for RF sickness near base station antennas) compared with non-users, and the risk of headache was also increased in those who had a longer daily call duration and higher daily call frequency (Wang et al., 2017). The same was also seen with cancer (Hardell et al., 2007). On the other hand, the symptoms caused by wireless smart meters were similar to those reported by people exposed to RF fields emitted by mobile phones (Lamech, 2014).

Investigations with radar and radio/television antennas

In studies carried out in the last century, occupational exposure of people to microwave radiation (RF) related to military, industrial and radio uses, as well as radio waves, showed several types of effects: an increase in spontaneous abortions, changes in red and white blood cell counts and an increase in childhood, testicular and other cancers. These findings suggest that RF exposures are potentially carcinogenic and have other health effects; the author recommends precautionary measures to avoid unnecessary exposure (Goldsmith, 1997). An analysis of particular locations of diagnosed neoplasms indicates significantly higher morbidity rates in the military exposed to RF for alimentary tract cancers, skin tumours, neoplasms and cerebral and haematological/lymphatic malignancies. For haematological/lymphatic malignancies, the difference in morbidity between exposed and unexposed military was the largest. This may suggest that spontaneous neoplasms develop faster in the exposed group, with a shorter latency period than in those not exposed. In fact, in exposed subjects, the disease occurs 5–10 years earlier (Szmigielski et al., 2001). On the other hand, children exposed to radar electromagnetic radiation had less developed memory and attention, their reaction time was slower and their neuromuscular apparatus endurance was decreased (Kolodynski and Kolodynska, 1996).

In several studies performed around radio and television antennas, there was a significant decrease in the risk of cancer and leukaemia with increasing distance to the antennas (Maskarinec et al., 1994; Dolk et al., 1997; Hocking and Gordon, 2000; Michelozzi et et al., 2002; Park et al., 2004). People exposed to a radio antenna shortwave broadcasting station
in Schwarzenburg (Switzerland) had sleep disturbances, which were more frequent in exposed than in unexposed subjects (Altpeter et al., 2000).

Thus, the coincidences of similar effects from studies with different sources of electromagnetic radiation (but with similar pulsed, polarized and modulated radiation), such as radar or radio/television antennas, reinforce the conclusions of this review. Non-ionizing EMF are among the fastest growing forms of environmental pollution, its increase around the world in recent years has been exponential (Bandara and Carpenter, 2018) and symptoms reported today may be classic microwave/RF sickness (Levitt and Lai, 2010).

RF exposure incidents among diplomats (Havana Syndrome)
From late 2016 through August 2017, US government personnel on a diplomatic mission in Havana, Cuba, reported neurological symptoms, including cognitive, balance, visual and hearing disturbances, sleep disturbances and headaches. These individuals appeared to have sustained injuries to generalized brain networks with no associated history of head trauma (Swanson et al., 2018). They complained of cognitive decline, fatigue and headache, especially after cognitive exertion, and in some cases tinnitus, nausea and balance problems (Dyer, 2018). This mysterious disease that affected US and Canadian diplomats in Cuba (and later also in China) has confused the FBI, the State Department and US intelligence agencies.

The reported facts seem consistent with pulsed RF/microwave as the source of injuries to the affected diplomats (Golomb, 2018). The same conclusion was later reached by the National Academy of Sciences (2020), who reported that many of the chronic or non-specific symptoms were consistent with known effects of RF, such as dizziness, headache, fatigue, nausea, anxiety, cognitive deficits and memory loss. In general, directed pulsed RF energy appears to be the most plausible mechanism to explain these cases. Such symptoms had already been described much earlier at the Moscow embassy (Lilienfeld et al., 1978; Johnson Lyakouris, 1998).

There are objective pathophysiological changes and health effects induced by EMF exposure that can biologically damage the organism and are noxious agents in healthy people (Belpomme and Irigaray, 2022).

Important laboratory studies
The United States National Toxicology Program (NTP) tested the two main modulation types used for mobile phones worldwide for GSM (2G) and UMTS (3G/4G), in a two-year rodent cancer bioassay under near-field exposure conditions; the experiments included additional assays for genotoxicity endpoints (Smith-Roe et al., 2020). They found clear evidence of carcinogenic activity, and more specifically malignant schwannomas of the heart, malignant gliomas of the brain and benign, malignant or complex pheochromocytomas (combined) of the adrenal medulla. They also found increased DNA damage (measured by the comet assay) in the frontal cortex of male mice, in the leukocytes of female mice and in the hippocampus of male rats, indicating that mobile phone EMF could cause DNA damage and consequent carcinogenesis. In a similar large carcinogenicity study by the Ramazzini Institute, Falcioni et al. (2018) examined far-field exposure to GSM 1800 MHz EMF and reported very similar results to the NTP study. Specifically, they also found increased incidence of tumours of the brain and heart in the mobile phone EMF-exposed Sprague-Dawley rats. Furthermore, these tumours are of the same histotype as those observed in some epidemiological studies on mobile phone users (Hardell et al., 2007).

Kostoff et al. (2020) emphasizes that most of the laboratory experiments conducted to date were not designed to identify the more severe adverse effects reflective of the real-life
operating environment in which wireless radiation systems operate, as many experiments do not include pulsing and modulation of the carrier signal and the majority do not account for synergistic adverse effects of other toxic stimuli.

Importance of studies with biological parameters and those performed on animals and plants
Despite the scientific evidence shown in the studies carried out in many countries by different teams of researchers that we have reviewed, several studies conclude that no effects are found and blame it on risk perception and the nocebo effect (Wiedemann et al., 2006; Kowall et al., 2012; Freudenstein et al., 2015; Dieudonné, 2016; Klaps et al., 2016; Koh et al., 2020). However, the nocebo effect is not supported by objective data (Belpomme and Irigaray, 2022), by the results of cancer studies (Eger et al., 2004; Wolf and Wolf, 2004; Dode et al., 2011; Li et al., 2012; Rodrigues et al., 2021), by studies on changes in haematological parameters (Gandhi et al., 2015; Meo et al., 2015; Taheri et al., 2017; Zothansiama et al., 2017), by hormonal changes after long-term exposure (Eskander et al., 2012), by salivary secretion (Singh et al., 2016) and by effects on fertility (Al-Quzwini et al., 2016). Many reviews on the health effects of mobile phones have reached the same conclusions regarding their effects on male infertility (El-Hamd and Aboeldahab, 2018). Unfortunately, the studies that allude to the nocebo effect seem to be the ones taken into account by the World Health Organization (WHO, 2015).

On the other hand, studies performed on animals or trees near base station antennas are especially important, because animals and plants cannot be aware of their proximity and therefore nocebo or psychosomatic effects cannot be attributed (Balmori, 2005, 2010; Balmori and Hallberg, 2007; Hässig et al., 2012; Lázaro et al., 2016; Waldmann-Selsam et al., 2016; Levitt et al., 2021).

Moreover, for these effects, perfectly plausible mechanisms of action have already been proposed. Plasma membrane calcium channels and other voltage-gated ion channels are irregularly activated/inactivated by man-made EMF in both animals and plants, increasing intracellular \([Ca^{2+}]\) and altering intracellular ion concentrations (Panagopoulos et al., 2002; 2021; Pall, 2016).

Under the influence of non-thermal intensities of microwave radiation, often there are important signals of some hazardous changes in cell metabolism. A significant increase of reactive oxygen species and nitrogen oxide generation in cells under non-thermal intensities has been detected both in vivo and in vitro (Yakimenko et al., 2011; Belpomme and Irigaray, 2022). Thus, the different findings clearly argue for a causal role of EMF in inducing free radical species, including overproduction of reactive oxygen and nitrogen species or suppression of antioxidant defence in cells (Belpomme and Irigaray, 2022). Furthermore, this exposure can result in DNA damage through oxidative stress with reactive oxygen species/free radical overproduction (Yakimenko et al., 2011; Kivrak et al., 2017; Panagopoulos et al., 2021).

The Precautionary Principle
The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is a private organization that issues exposure guidelines that are then adopted by governments, but it has been accused of having conflicts of interest (Hardell & Carlberg 2020; Hardell et al. 2021). The ICNIRP (2010, 2020) limits are thousands of times above the levels where effects are recorded for both extremely low frequency and RF man-made EMF and account only for thermal effects, whereas the vast majority of recorded effects are non-thermal. These existing guidelines for public health protection only consider the effects of acute intense (thermal) exposures and do not protect from lower level long-term exposures (Israel et al., 2011;
The exposure duration is crucial to assess the induced effects. The Precautionary Principle is one of the fundamental principles of the European Union, governing policies related to the environment, health and food safety (Harremoes et al., 2013). This principle enables decision-makers to adopt precautionary measures when the scientific evidence regarding an environmental or human health factor is not certain regarding its safety. Therefore, despite the existing ample and rapidly increasing scientific evidence, no significant progress has been made over all these years, at least at the level of guidelines issued by the responsible authorities and official regulatory bodies. Some authors have pointed out that the source of funding correlates with study findings, and many systematic reviews and meta-analyses in this field have failed to correct for this source of funding bias, which has likely underestimated the evidence for causation (Carpenter, 2019). A growing number of scientists have been calling internationally on governments to raise their safety standards for RF-EMF (Blank et al., 2015; Hardell and Nyberg, 2020; Frank, 2021). Thus, there is an urgent need to adopt the Precautionary Principle and impose more restrictive levels (Zinelis, 2010, Yakymenko et al., 2011; Blank et al., 2015; Starkey, 2016).

Conclusion

In the current circumstances, it seems that the scientific experts in the field are very clear about the serious problems we are facing and have expressed this through important appeals (Blank et al., 2015; Hardell and Nyberg, 2020). However, the media, the responsible organizations (World Health Organization, 2015) and the governments are not transmitting this crucial information to the population, who remain uninformed. For these reasons, the current situation will probably end in a crisis not only for health but also for the technology itself, as it is unsustainable and harmful to the environment and the people.
Figure 1. Results on effects according to the study type considered
References


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Highlights

- This study updates the knowledge on the effects of base station antennas on humans
- Studies performed with mobile phone base stations close to apartments were selected
- Considering all the studies reviewed globally (n=38), 73.6% (28/38) showed effects
- The effects are radiofrequency sickness, cancer and changes in biochemical parameters
- Similar effects from RF by different sources reinforce the conclusions of this review
Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: