Human populations are increasingly exposed to microwave/radiofrequency (RF) emissions from wireless communication technology, including mobile phones and their base stations. By searching PubMed, we identified a total of 10 epidemiological studies that assessed for putative health effects of mobile phone base stations. Seven of these studies explored the association between base station proximity and neurobehavioral effects and three investigated cancer. We 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. None of the studies reported exposure above accepted international guidelines, suggesting that current guidelines may be inadequate in protecting the health of human populations. We believe that comprehensive epidemiological studies of long-term mobile phone base station exposure are urgently required to more definitively understand its health impact. 

**Key words**: base stations; electromagnetic field (EMF); epidemiology; health effects; mobile phone; radiofrequency (RF); electromagnetic radiation.

**INTRODUCTION**

Mobile phone base stations are now found ubiquitously in communities worldwide. They are frequently found near or on shops, homes, schools, daycare centers, and hospitals (Figure 1). The radiofrequency (RF) electromagnetic radiation from these base stations is regarded as being low power; however, their output is continuous.1 This raises the question as to whether the health of people residing or working in close proximity to base stations is at any risk.

**METHODS**

By searching PubMed and using keywords such as base station, mast, electromagnetic field (EMF), radiofrequency (RF), epidemiology, health effects, mobile phone, and cell phone, and by searching the references of primary sources, we were able to find only 10 human population studies from seven countries that examined the health effects of mobile phone base stations. Seven of the studies explored the association between base station proximity and neurobehavioral symptoms via population-based questionnaires; the other three retrospectively explored the association between base station proximity and cancer via medical records. A meta-analysis based on this literature is not possible due to differences in study design, statistical measures/risk estimates, exposure categories, and endpoints/outcomes. The 10 studies are therefore summarized in chronological order (Table 1).

**RESULTS AND DISCUSSION**

We found epidemiological studies pertaining to the health effects of mobile phone base station RF emissions to be quite consistent in pointing to a possible adverse health impact. Eight of the 10 studies reported increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at distances < 500 meters from base stations. The studies by Navarro et al.,2 Santini et al.,3 Gadzicka et al.,4 and Hutter et al.5 reported differences in the distance-dependent prevalence of symptoms such as headache, impaired concentration, and irritability, while Abdel-Rassoul et al.6 also found lower cognitive performance in individuals living ≤ 10 meters from base stations compared with the more distant control group. The studies by Eger et al.7 and Wolf and Wolf8 reported increased incidence of cancer in persons living for several years < 400 meters from base stations. By contrast, the large retrospective study by Meyer et al.9 found no increased incidence of cancer near base stations in Bavaria. Blettner et al.10 reported in Phase 1 of their study that more health problems were found closer to base stations, but in Phase 211 concluded that measured EMF emissions were not related to adverse health effects (Table 1). Each of the 10 studies reviewed by us had various strengths and limitations as summarized in Table 1. Per-
taining to those base station studies in which EMF measurements were not carried out, it should be noted that distance is not the most suitable classifier for exposure to RF-EMF. Antennae numbers and configurations, as well as the absorption and reflection of their fields by houses, trees, or other geographic hindrances may influence the exposure level. Further, self-estimation of distance to nearest base station is not the best predictor of exposure since the location of the closest base station is not always known. Such exposure misclassification inevitably biases any association towards null. Multiple testing might also produce spurious results if not adjusted for, as might failure to adjust for participant age and gender. Latency is also an important consideration in the context of cancer incidence following or during a putative environmental exposure. In this regard, the study by Meyer et al. found no association between mobile phone base station exposure and cancer incidence, but had a relatively limited observation period of only two years. On the other hand, the studies by Eger et al. and Wolf and Wolf found a significant association between mobile phone base station exposure and increased cancer incidence, although the approximate five-year latency between base station exposure and cancer diagnosis appears to be unexpectedly short in both of these studies.

Other problems in several population-based questionnaires are the potential for bias, especially selection and participation biases, and self-reporting of outcomes in combination with the exposure assessment methods used. For example, regarding limitations in exposure assessment, in a large two-phase base station study from Germany, of the Phase 1 participants (n = 30,047), only 1326 (4.4%) participated with a single “spot” EMF measurement recorded in the bedroom for Phase 2. Further, health effect contributions from all relevant EMF sources and other non-EMF environmental sources need to be taken into account. We acknowledge that participant concern instead of exposure could be the triggering factor of adverse health effects, however this “nocebo effect” does not appear to fully explain the findings. Further, the biological relevance of the overall adverse findings (Table 1) is supported by the fact that some of the symptoms in these base-station studies have also been reported among mobile phone users, such as headaches, concentration difficulties, and sleep disorders. Finally, none of the studies that found adverse health effects of base stations reported RF exposures above accepted international guidelines, the implication being that if such findings continue to be reproduced, current exposure standards are inadequate in protecting human populations.
<table>
<thead>
<tr>
<th>Publication (Year; Country)</th>
<th>Clinical Assessment</th>
<th>Study Design</th>
<th>Base Station Details</th>
<th>Participants</th>
<th>EMF Measured</th>
<th>Key Findings</th>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navarro² (2003; Spain)</td>
<td>Neuro-behavioral</td>
<td>Survey-questionnaire</td>
<td>GSM-DCS 1800 MHz</td>
<td>101</td>
<td>Yes</td>
<td>More symptoms with closer proximity to base station (&lt; 150 m)</td>
<td>Detailed questionnaire, EMF measured, distances studied²</td>
<td>Low participation, self-estimated distances, subjects aware²</td>
</tr>
<tr>
<td>Santini² (2003; France)</td>
<td>Neuro-behavioral</td>
<td>Survey-questionnaire</td>
<td>n/s</td>
<td>530</td>
<td>No</td>
<td>More symptoms with closer proximity to base station (&lt; 300 m)</td>
<td>Detailed questionnaire, distances &amp; other EMF exposures assessed</td>
<td>As above, plus no EMF measurement, no base station details</td>
</tr>
<tr>
<td>Eger⁷ (2004; Germany)</td>
<td>Cancer incidence</td>
<td>Retrospective case review</td>
<td>GSM 935 MHz</td>
<td>967</td>
<td>No</td>
<td>3 x risk of cancer after 5 yrs of exposure (&lt; 400 m); early age of cancer diagnosis</td>
<td>Maximum beam intensity calculated, reliable cancer data collection</td>
<td>Other environmental risk factors not assessed; analysis not adjusted for age and sex</td>
</tr>
<tr>
<td>Wolf &amp; Wolf⁶ (2004; Israel)</td>
<td>Cancer incidence</td>
<td>Retrospective case review</td>
<td>TDMA 850 MHz</td>
<td>1844</td>
<td>Yes</td>
<td>&gt; 4 x risk of cancer after 3–7 yrs exposure (&lt; 350 m); early age of cancer diagnosis</td>
<td>Reliable cancer &amp; demographic data, no other major environmental pollutants identified</td>
<td>Not all environmental risk factors assessed; possible selection bias; no age, sex adjustment</td>
</tr>
<tr>
<td>Gadzicka⁴ (2006; Poland)</td>
<td>Neuro-behavioral</td>
<td>Survey-questionnaire</td>
<td>n/s</td>
<td>500</td>
<td>No</td>
<td>More headache with proximity &lt; 150 m; nocebo unlikely³</td>
<td>Detailed questionnaire, EMF measured, nocebo studied</td>
<td>Subjects aware, no base station details</td>
</tr>
<tr>
<td>Hutter⁵ (2006; Austria)</td>
<td>Neuro-behavioral</td>
<td>Cross-sectional</td>
<td>900 MHz</td>
<td>336</td>
<td>Yes</td>
<td>Headaches &amp; impaired concentration at higher power density; nocebo unlikely</td>
<td>Detailed questionnaire and testing, EMF measured, nocebo effect studied</td>
<td>Subjects aware, low participation rate</td>
</tr>
<tr>
<td>Meyer⁸ (2006; Germany)</td>
<td>Cancer incidence</td>
<td>Retrospective case review</td>
<td>n/s</td>
<td>177,428</td>
<td>No</td>
<td>No increased cancer incidence in municipalities with or without base stations</td>
<td>Wide population assessed (Bavaria)</td>
<td>Observation period only 2 years, vague definitions of exposure, exposure onset unknown, distance to base station unknown</td>
</tr>
<tr>
<td>Abdel-Rassoul⁶ (2007; Egypt)</td>
<td>Neuro-behavioral</td>
<td>Cross-sectional</td>
<td>n/s</td>
<td>165</td>
<td>Yes</td>
<td>More symptoms &amp; lower cognitive performance if living under or &lt; 10 m from base station</td>
<td>Detailed questionnaire and testing, EMF measured, nocebo effect studied</td>
<td>Exact base station details, low number of participants</td>
</tr>
<tr>
<td>Blettner¹⁰ (2009; Germany)</td>
<td>Neuro-behavioral</td>
<td>Cross-sectional</td>
<td>n/s</td>
<td>30,047</td>
<td>No</td>
<td>More health complaints closer to base station (&lt; 500 m)</td>
<td>Wide population assessed, detailed survey, nocebo effect assessed</td>
<td>EMF measurements not carried out (see phase II in Berg-Beckhoff et al., 2009; below)</td>
</tr>
<tr>
<td>Berg-Beckhoff¹¹ (2009; Germany)</td>
<td>Neuro-behavioral</td>
<td>Cross-sectional</td>
<td>GSM 900 MHz GSM 1800 MHz UMTS 1920–1980 MHz</td>
<td>1326</td>
<td>Yes</td>
<td>Health effects probably caused by stress and not by RF-EMF</td>
<td>Measured EMF emissions, standardized questionnaires</td>
<td>Low participation, no detailed list of symptoms published, single “spot” measurement in one place in dwelling, no occupational exposure assessed, time lag from assessment of symptoms and EMF measurement</td>
</tr>
</tbody>
</table>

n / s = not specified.

²“Distance” refers to distance between base station and subjects’ households.

³“Subjects aware” refers to study participants being aware of the nature of the study.

⁴“Nocebo” effect unlikely because the majority of subjects in the study reported little or no concern for base station proximity.
Despite variations in the design, size and quality of these studies as summarized in Table 1, it is the consistency of the base-station epidemiological literature from several countries that we find striking. In particular, the increased prevalence of adverse neurobehavioral symptoms or cancer in populations living at distances < 500 meters from base stations found in 80% of the available studies. It should be pointed out that the overall findings of health problems associated with base stations might be based on methodological weaknesses, especially since exposure to RF electromagnetic radiation was not always measured.

There are some proposed mechanisms via which low-intensity EMF might affect animal and human health, but full comprehensive mechanisms still remain to be determined. Despite this, the accumulating epidemiological literature pertaining to the health effects of mobile phones suggests that previous exposure standards based on the thermal effects of EMF should no longer be regarded as tenable. In August 2007, an international working group of scientists, researchers, and public health policy professionals (the BioInitiative Working Group) released its report on EMF and public health policy professionals (the BioInitiative Report). It provided detailed scientific information on health impacts when people were exposed to electromagnetic radiation hundreds or even thousands of times below limits currently established by the FCC and International Commission for Non-Ionizing Radiation Protection in Europe (ICNIRP). The authors reviewed more than 2000 scientific studies and reviews, and have concluded that: (1) the existing public safety limits are inadequate to protect public health; and (2) from a public health policy standpoint, new public safety limits and limits on further deployment of risky technologies are warranted based on the total weight of evidence. A precautionary limit of 1 mW/m² (0.1 microW/cm² or 0.614 V/m) was suggested in Section 17 of the BioInitiative Report to be adopted for outdoor, cumulative RF exposure. This limit is a cautious approximation based on the results of several human RF-EMF studies in which no substantial adverse effects on well being were found at low exposures akin to power densities of less than 0.5 – 1 mW/m². RF-EMF exposure at distances > 500 m from the types of mobile phone base stations reviewed herein should fall below the precautionary limit of 0.614 V/m.

CONCLUSIONS

References


