

# The Influence of Electromagnetic Field Pollution on Human Health: A Systematic Review

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## ABSTRACT

**Objective:** Recent technological advances have exponentially expanded globally; harbouring upon Electromagnetic fields (EMF). The utilization of Electromagnetic field has become universal from everyday usage of electronic appliances such as micro wave ovens, tablets and portable computers to telecommunication systems mobile phone towers, radio- television broadcast systems and electronic power transmission systems resulting in electromagnetic field and associated radiations. EMF can have biological effects on cell at microlevel and have the potential ability to cause cell dysfunction manifesting in various biological effects. This review tried to gather evidence from the existing literature about the biological effects of EMF on human health.

**Materials and Methods:** We did extensive literature search using PubMed and Cochrane database using key words, “electromagnetic fields”, “Extremely low frequency electromagnetic fields (ELF-EMFs)”, “biological effects”, “health effects”, “public health”. We included 20 studies conducted from Dec 2009 to Dec 2019 in our systematic review. Data from each study was extracted by two independent researchers and discrepancies were resolved by consensus.

**Results:** Significant biological effects of EMF exposure were reported on human health ranging from anxiety, depression, sleep disturbance, increased risk of Alzheimer’s disease and ALS (Amyotrophic Lateral Sclerosis), hypersensitivity to infertility and increased risk of multiple carcinomas.

**Conclusion:** Application of preventive measures in order to minimize the exposure becomes the need of the hour especially so in occupational settings.

**Keywords:** Electromagnetic fields; health effects; biological effects; carcinogen (Siriraj Med J 2021; 73: 485-492)

## INTRODUCTION

Since the arrival of 20<sup>th</sup> century everyone is exposed to a complex mix of weak electric and magnetic fields, at home as well as at work places, from the generation and transmission of electricity, domestic appliances and industrial equipment, to telecommunications and broadcasting resulting in electromagnetic field and associated radiations. With ubiquitous expansion of current technology system globally in the last few decades, EMF has crept up as a new type of pollution in the physical environment due to resulting electromagnetic radiations. This anthropogenic pollution is much stronger

than the known natural sources of electromagnetic fields or radiation. One of the first reports of their potentially harmful effects on living organisms was an epidemiological research report published in 1979 by Wertheimer and Leeper.<sup>1</sup> They studied the health status of children from Denver (Colorado, USA), who lived in homes exposed to magnetic fields of high intensities and concluded that the children exposed to higher intensity magnetic fields had slightly higher risks of developing leukaemia.<sup>1</sup>

Anthropogenic electromagnetic fields can be classified by their physical parameters such as frequency, and intensity. They can range from extremely low frequency (associated

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with electricity supplies and electrical appliances) to low, medium, high, and extremely high frequency (mostly associated with wireless communication). Electronic devices such as smartphones, tablets, microwave ovens, radio, and television sets emit low intensity electromagnetic radiation at frequencies from 300 MHz to 300 GHz that can be associated with microwaves. On the other hand, power transmission lines and electric devices are strong sources of electromagnetic fields and radiation of much lower frequencies but much higher intensities. Electromagnetic fields and/or electromagnetic radiation, as electromagnetic pollution, affect various elements of the environment and living organism. EMF pollution in public health literature refers to the hazard bestowed by non-ionising radiations with a frequency towards the lower half of the electromagnetic spectrum. Tiny electrical circuits exist in the human body that occur as part of the normal bodily functions like transmission of electric impulses for brain activities, heart beating and even due to chemical reactions for digestion of food. Low-frequency electric fields influence the human body which is made up of charged particles, so influence the distribution of electric charges and causes small currents inside. Similarly, Low-frequency magnetic fields may also induce circulating currents within the body depending on the intensity of the magnetic field. Both electric and magnetic fields induce voltages and currents in the body that are usually very small. However, if sufficiently large, these currents could cause stimulation of nerves and muscles or affect other biological processes. Commonly, the effects of EMF radiations can be broadly classified as thermal and non-thermal effects. Though thermal effects are well documented in public health literature the non-thermal effect poses greater challenge for the upcoming research as there are conflicting results of different epidemiological studies done on this matter.

We are currently living under this large gamut of EMF with a limited knowledge of its biological impact. Although in-vitro studies have proven negative impact of EMF at cellular levels, lacunae exist in providing evidence towards possible adverse outcomes in terms of health. Hence, it becomes very important to appropriately determine the nature and related side effects of electromagnetic pollution and its impact on human health. The International Agency of Research on Cancers (IARC) has declared EMF as “Possibly carcinogenic to human health (category 2B)”.<sup>2</sup> The effect of these radiation on environment is of course research-worthy yet practically difficult to conduct.

**Objective:** We conducted this systematic review with the objective to identify and map the available evidences

regarding the possible biological effect of EMF pollution on human health so that its public health effects could be addressed.

## MATERIALS AND METHODS

### Literature search

We conducted a systematic search of Medline database and the Cochrane Library in January 2020 to identify all relevant peer-reviewed papers published using key words, “electromagnetic fields”, “Extremely low frequency electromagnetic fields (ELF-EMFs)”, “biological effects”, “health effects”. The key words were arranged in different Boolean combinations with different search phrases. The search was further refined using filters/ mesh terms, “free full text”, “10 years”, “English”, “MEDLINE”, “Humans”.

**Inclusion and exclusion criteria:** We included human laboratory trials and epidemiological studies published in English in last 10 years from Dec 2009 to Dec 2019. The health effects due to EMF were then rearranged in line with different human systems affected. However, we excluded in-vitro studies, studies in animals and studies discussing therapeutic effects of EMF.

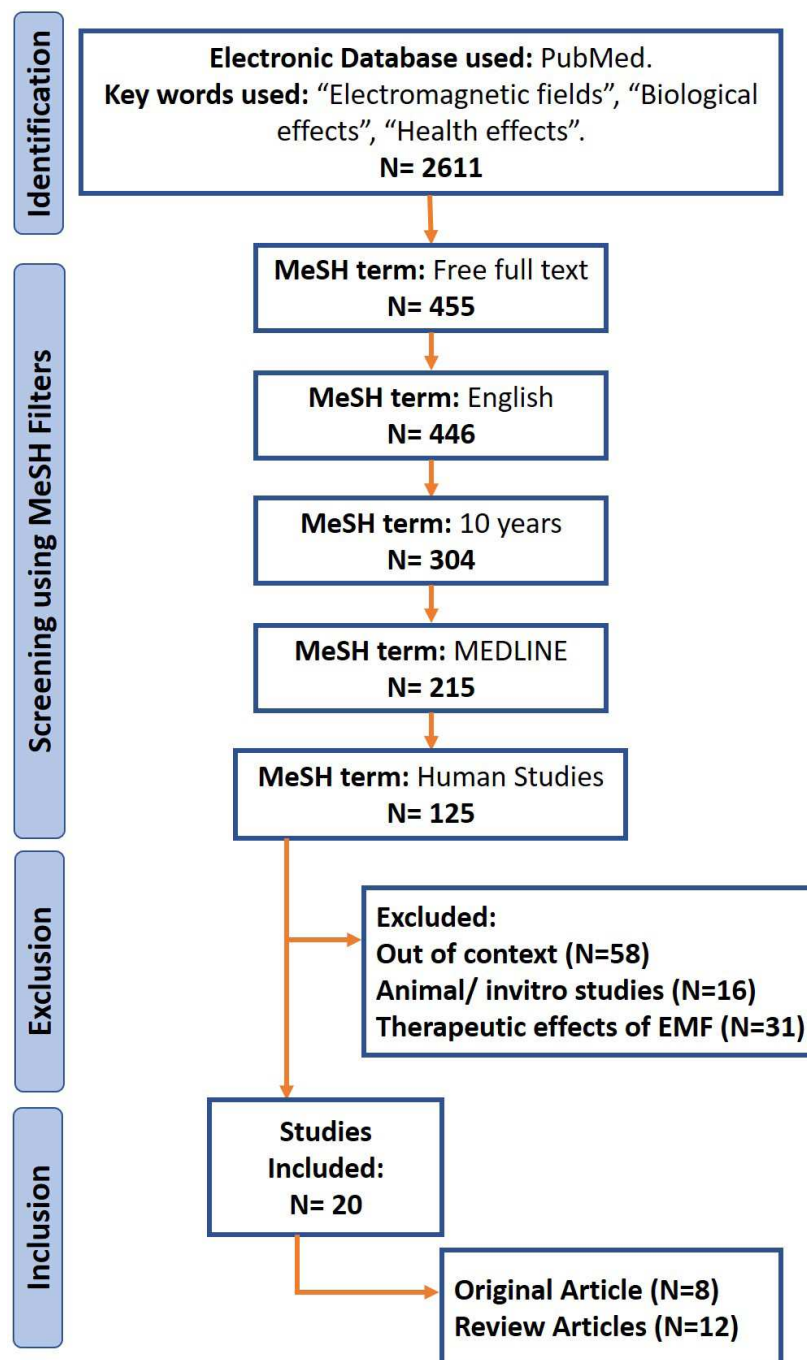
**Data extraction:** The data from each study were extracted independently by two researchers and recorded. The form extracted information about study design study sample, sampling procedure, exposure, results and health effects. Differences concerning data extraction were resolved by consensus.

**Selection of studies:** In total, 2611 potentially relevant abstracts were identified; from where 445 full text articles were considered; based on our inclusion and exclusion criteria 20 studies were finally included in the review (Fig 1). Of the 20 articles included in the analyses, 8 were original studies and 12 were review articles.

## RESULTS

Multiple adverse effects of EMF on different human organ systems have been reported by different studies. Different varieties of biological effects were observed in presence of different type of electromagnetic radiations. Findings from various epidemiological studies and their major gaps have been listed in Table 1. We identified, seven original studies out of the eight, included in the review, suggested possible association of presence of various physical symptoms and cell morphology alteration with exposure to EMF.<sup>3-8</sup> One accepted mechanism of action of EMF to exert their non thermal biological effect is via breaking DNA strands in cell type dependent manner.<sup>9</sup>

Ten out of 12 review studies included in the review suggested possibility of linkage of EMF with cellular pathways like apoptosis and other cellular regulatory



**Fig 1.** Flowchart showing the identification and selection of studies on the health effects of exposure to electromagnetic fields (EMF)

mechanism which may lead to carcinogenesis.<sup>10-19</sup> One study also reported increased reactive oxygen species on exposure to EMF in human cell lines leading to cellular damage.<sup>11</sup> However, two review articles reported unlikely or inconsistent findings of any effect of EMF exposure on cognitive functions and brain tumours.<sup>20,21</sup>

We identified multiple studies conducted at different places and time that have provided evidence regarding effects of EMF on multiple organ system. Though WHO and its auxiliary organisations have repeatedly told that the effect is not detrimental to health, but it didn't satisfy

a large number of researchers who have explained that only short-term effects had been taken into consideration in the epidemiological studies, not the long term and non-thermal effects, thus disapproving WHO's stance on the matter.<sup>22</sup> Based on the studies included in the review we summarised the potential effects of EMF on various organ systems. (Fig 2)

#### Effects on nervous system





Studies have also reported a positive correlation between EMF exposure and neurodegenerative diseases

**TABLE 1.** Summary of various epidemiological studies included in the systematic review.

Authors Article Types Publication Year	Findings	Challenges in understanding the biological effects of EMF radiations
Bogers RP et al. <sup>6</sup> (Original Article), 2018	<ul style="list-style-type: none"> <li>Possible association of Nonspecific Physical symptoms (Positive or negative) with EMF exposure</li> </ul>	<ul style="list-style-type: none"> <li>Small sample size (n=7) due complex study design including use of exposimeters to assess the exposure.</li> </ul>
Lasalvia M et al. <sup>5</sup> (Original Article), 2018	<ul style="list-style-type: none"> <li>Possible alterations of morphology of lympho-monocytes of exposure to microwave radiation.</li> </ul>	<ul style="list-style-type: none"> <li>Larger samples required to assess the biological consequences of findings.</li> </ul>
Jazi SD et al. <sup>27</sup> (Original Article), 2017	<ul style="list-style-type: none"> <li>No effect of EMF on physiological tremor and EEG</li> </ul>	<ul style="list-style-type: none"> <li>Generalization of the study findings was limited to small sample size ( ) and nature of the study</li> </ul>
Kapri-Pardes E et al. <sup>7</sup> (Original Article), 2017	<ul style="list-style-type: none"> <li>Evidence of potential of ELF-EMF towards cellular proliferation and oncogenic transformation.</li> </ul>	<ul style="list-style-type: none"> <li>No sufficient rise in ERK1/1 phosphorylation on EMF exposure sufficient to justify oncogenic potential.</li> </ul>
Fang Q et al. <sup>3</sup> (Original Article), 2016	<ul style="list-style-type: none"> <li>Change in RR interval on short term exposure to EMF.</li> <li>No change in rest of the ECG intervals on EMF exposure.</li> </ul>	<ul style="list-style-type: none"> <li>In view of overlapping ECG frequency and ELF-EMF operating frequency, it is difficult to conclude definitive effect of EMF on ECG.</li> </ul>
Luo Q et al. <sup>2</sup> (Original Article), 2013	<ul style="list-style-type: none"> <li>EMF exposure adversely affects placental functions and foetal development among pregnant mothers.</li> </ul>	<ul style="list-style-type: none"> <li>Altered protein expression on foetus cannot be verified due in ethical concerns.</li> </ul>
Balamuralikrishnan B et al. <sup>4</sup> (Original Article), 2012	<ul style="list-style-type: none"> <li>Genotoxic potential of ELF-EMF in peripheral lymphocytes among workers exposed to prolonged low level non ionizing radiation</li> </ul>	<ul style="list-style-type: none"> <li>It was a case control study, however only 20 controls for 50 exposed were taken. Control group could have been increased.</li> </ul>
Augner C Et al. <sup>8</sup> (Original Article), 2010	<ul style="list-style-type: none"> <li>Higher incident of psychological strain and anxiety among people living 100 meters or less, from the tele-communication base stations.</li> </ul>	<ul style="list-style-type: none"> <li>The findings were generated with the help of participant's subjective outlook regarding the EMF exposure.</li> </ul>
Naarala J, et al. <sup>10</sup> (Review Article), 2019	<ul style="list-style-type: none"> <li>Linkage of Radiofrequency MF with pathways like apoptosis, cellular regulation and cytoskeleton maintenance.</li> <li>Effects of EMF on circadian rhythm and sleep cycle.</li> </ul>	<ul style="list-style-type: none"> <li>Lack of consistency regarding effects of EMF exposure by different studies.</li> <li>Inhomogeneous study designs.</li> </ul>
Singh R et al. <sup>14</sup> (Review Article), 2018	<ul style="list-style-type: none"> <li>Possible mechanism of action of non-thermal effects can be production of reactive oxygen species.</li> <li>Effect of EMF on reproductive system by causing decreased sperm motility, viability as well as altered sperm morphology.</li> </ul>	<ul style="list-style-type: none"> <li>Different exposure parameters, variations in body structures and environment.</li> </ul>

**TABLE 1.** Summary of various epidemiological studies included in the systematic review. (Continue)

Authors Article Types Publication Year	Findings	Challenges in understanding the biological effects of EMF radiations
Santini SJ et al. <sup>18</sup> (Review Article), 2018	<ul style="list-style-type: none"> <li>Cellular effects like altered molecular pathways, apoptosis and dysregulated cell cycle.</li> <li>Raised reactive oxygen species. Possible role of EMF as co-carcinogen.</li> <li>Increased risk of neurodegenerative diseases, autism.</li> <li>Possible effect of both male and female reproductive systems.</li> </ul>	<ul style="list-style-type: none"> <li>Different biological models used in different settings, diverse exposure.</li> <li>Controversial findings among various studies.</li> </ul>
Kesari KK et al. <sup>13</sup> (Review Article), 2018	<ul style="list-style-type: none"> <li>Detrimental effect of EMF on quality of sperms including count, morphology and motility.</li> </ul>	<ul style="list-style-type: none"> <li>Even in presence of significant evidence, the true mechanism behind effect of EMF on reproductive system inaccessible.</li> </ul>
Wang H et al. <sup>11</sup> (Review Article), 2017	<ul style="list-style-type: none"> <li>Increased levels of reactive oxygen species on exposure to EMF in majority of the reviewed research.</li> </ul>	<ul style="list-style-type: none"> <li>Disparities among various studies which could be due to magnetic field type/ intensity/frequency.</li> </ul>
Carlberg M et al. <sup>19</sup> (Review Article), 2017	<ul style="list-style-type: none"> <li>Potential association of gliomas and EMF exposure in the basis of nine Bradford Hill viewpoints.</li> </ul>	<ul style="list-style-type: none"> <li>Findings are based on Hills viewpoint of causality and analyses secondary data</li> </ul>
Medeiros LN et al. <sup>12</sup> (Review Article), 2015	<ul style="list-style-type: none"> <li>Association between EMF exposure and tinnitus, especially in persons with electromagnetic hypersensitivity.</li> </ul>	<ul style="list-style-type: none"> <li>Prospective cohort studies are further required for providing definitive evidence of the findings.</li> </ul>
Teepen JC, et al. <sup>16</sup> (Review Article), 2012	<ul style="list-style-type: none"> <li>Increased potential risk of Childhood Leukaemia for EMF exposure although its causal association cannot be confirmed.</li> </ul>	<ul style="list-style-type: none"> <li>Limited epidemiological studies on impact of EMF with inbuilt biases in the present studies.</li> </ul>
Pall ML et al. <sup>15</sup> (Review Article), 2015	<ul style="list-style-type: none"> <li>Non thermal biological effects of EMF need to be emphasized, esp. the genotoxic potential in presence of vast array of literature with conflicting results.</li> </ul>	<ul style="list-style-type: none"> <li>Emphasis of selection of only consistent studies while addressing the research question with preformed</li> </ul>
Vijaylaxmi et al. <sup>17</sup> (Review Article), 2014	<ul style="list-style-type: none"> <li>Even in presence of contrasting findings from different group of experts about the biological effects of EMF, a preventive approach towards the same remains the key.</li> </ul>	<ul style="list-style-type: none"> <li>It was compilation of the various guidelines and conclusions of studies on the biological effects of RF exposures, from various national and international expert groups.</li> </ul>
Swerdlow AJ et al. <sup>21</sup> (Commentary), 2011	<ul style="list-style-type: none"> <li>Unlikely evidence of increased brain tumours among adults.</li> </ul>	<ul style="list-style-type: none"> <li>Presence of recall misclassification in the case control studies, limited time duration.</li> </ul>
Regel SJ et al. <sup>20</sup> (Review Article), 2011	<ul style="list-style-type: none"> <li>Inconsistent findings of any effect of EMF exposure and cognitive functions.</li> </ul>	<ul style="list-style-type: none"> <li>Reason behind the inconsistent findings could be lack of validated tools, study designs and different sample sizes.</li> </ul>

Sources of EMF emission: Smart meters, WLAN, Mobile phones, Video Display Units, Base Stations, Radio stations, Microwave, Electric lines and wiring.	
 <b>Nervous System</b>	 <b>Cardiovascular &amp; Circulatory System</b>
Increased Risk of: <ul style="list-style-type: none"> <li>✓ Amyotrophic Lateral Sclerosis.</li> <li>✓ Altered sleep cycles.</li> <li>✓ Neurodegenerative diseases.</li> <li>✓ Tinnitus and other Hearing disorder.</li> </ul>	<ul style="list-style-type: none"> <li>✓ Change in RR interval.</li> <li>✓ Genotoxic potential in peripheral lymphocytes.</li> <li>✓ Morphological changes in lymphomonocytes.</li> </ul>
 <b>Reproductive System</b>	 <b>EMF &amp; Cancers</b>
<ul style="list-style-type: none"> <li>✓ Adverse effect on quality of spermatozoa.</li> <li>✓ Decreased sperm motility</li> <li>✓ Female infertility.</li> <li>✓ Increased chances of spontaneous abortions</li> </ul>	Increased chances of: <ul style="list-style-type: none"> <li>✓ Gliomas, parotid cancers.</li> <li>✓ Increased risk of intracranial tumours.</li> <li>✓ Increased risk of Childhood Leukaemia.</li> </ul>

**Fig 2.** Figure showing possible adverse effects of EMF on different organ system.

and autism.<sup>18,23</sup> Gunnarsson LG et al in their study on occupational exposure of EMF reported 10% increase in the risk of ALS (Amyotrophic Lateral Sclerosis) and Alzheimer's disease due to exposure.<sup>24</sup> In an Indian study amongst school going students, "Ringxiety" or phantom ringing is seen in the students frequently using mobile phones in classroom and library.<sup>25</sup> Augner C et al, also reported higher psychological stress and anxiety among those living near base stations.<sup>8</sup> Medeiros LN et.al, in a review, reported association of long-term mobile phone use and tinnitus and other hearing disorders.<sup>12</sup> A study by Reale et.al, also provide data on potential effect of ELF- EMF on neurodegenerative processes which further needs to be established with the help of experimental models.<sup>20</sup> EMFs have also been reported to alter pineal melatonin concentration, affect sleep cycle, lower mood, reduced concentration, and depression; decrease in release of melatonin hampers maintaining the molecular structure of DNA strands, entitling EMFs as teratogenic and mutagenic.<sup>26</sup> A study by Jazi AD et al., however reported no effect of EL-EMF on physiological tremors and EEG.<sup>27</sup>

### Effects on reproductive system

Kesari et al. have reported negative effect of EMF on male fertility due to adverse effect on quality of spermatozoa.<sup>13</sup> A decrease in the normal sperm morphology, motility and count on exposure to EMF including mobile phones has also been reported in literature.<sup>14,18</sup> Another case

control study done in Iran reported 4 times higher risk of infertility among women living within 500 mts proximity of high voltage power lines in comparison to women living at more than 1,000 mts distance.<sup>28</sup> Clinical studies on pregnant women exposed to ELF RF like Video display terminal (VDT) have indicated a significant increase in spontaneous abortions.<sup>29</sup> Exposure of EMF in early embryo stage may also have an adverse effect on nervous system development and cellular proliferation.<sup>30</sup>

### Effect of cardiovascular and circulatory system

Fang et al in their study reported a significant change in RR interval on ECG on short term exposure to ELF-EMF, with no significant change on other intervals. However, physiological implication to the above findings requires further research.<sup>3</sup> Evidence also supports genotoxic potential of ELF-EMF in peripheral lymphocytes among workers exposed to prolonged low level non-ionizing radiation.<sup>4</sup> Possible effect of EMF exposure on the lymphomonocyte morphology was also reported but was limited to further research in terms of EMF type/ intensity/ frequency, etc.<sup>5</sup>

### Electromagnetic Hypersensitivity Syndromes (EHS)

Some individuals reported dermatological symptoms like redness, itching relating to exposure to EMFs termed as Electromagnetic Hypersensitivity syndromes (EHS). It was sometimes associated with or without vegetative or neurasthenic symptoms like nausea, general weakness,

dizziness, nystagmus, sometimes even haemoptysis and paralysis.<sup>2</sup> Bogers et.al, also reported association of non-specific physical symptoms (including, headache, fatigue and dizziness that cannot be explained by other medical condition), with radio frequency electromagnetic fields.<sup>6</sup> However, after conducting several double-blinded cohort studies, the causal association of EHS with EMF could not be established. EHS was then regarded as the consequence of predicament of assuming harmfulness of EMF rather than EMF itself by many leading health professional and scientific bodies.<sup>31</sup>

### EMF and cancers

A study by Kapri-Pardes et al., yielded some evidence of potential of ELF-EMF towards cellular proliferation and oncogenic transformation.<sup>7</sup> Teepen JC, et al, also provided epidemiological evidence of higher population attributable risk of Childhood Leukaemia among children exposed to ELF-EMF levels above 0.3  $\mu$ T.<sup>16</sup> The Interphone study published in 2010, reported more than double the risk of brain Glioma in the people using mobile phones for more than 10 years.<sup>32</sup> A meta-analysis done by Bortkiewicz A, et al, also provided evidence increased risk of increased risk of intracranial tumours with long term use of mobile phones.<sup>33</sup> However, many other studies proved inconclusive evidences of mobile phone usage and cancers.<sup>15,21,34</sup> A study relating occurrence of cancers (Glioma, Acoustic Neuroma and Parotid gland cancers) with respect to the residential distance from GSM or UMTS found no relationship between the occurrence of cancer and various distances.<sup>35</sup> Carlberg M et al., using Bradford Hill viewpoints also concluded a positive association of gliomas and EMF exposure.<sup>19</sup>

### DISCUSSION

As, there are multiple sources of EMF in any particular residence or workplace, proper epidemiological evaluation of this matter is quite ambiguous. As the time of use of electronic appliances and telecommunication tools like mobile phones and other EMF devices will increase in coming years, we are exposed to EMF radiation from multiple sources simultaneously every day at work and home. So accurate data regarding EMF pollution from any epidemiological studies could not possibly made in real human population. Experimental studies indicate that short-term exposure at the levels present in the environment or in the home do not cause any apparent detrimental effects. Thus, till the time a definitive health effect has been proven, considering a high index of suspicion, a need arise for proper legislative measure

that should be taken to reduce usage of materials that contributes to electromagnetic field pollution. Such as, limitation of numbers of radio stations in crowded area or base station in public place. Electric lines and wiring should be done as such that EMF emission should be least. IEC activities should be undertaken targeting young population to decrease mobile phone time in their daily life, which is increasing day-by-day. Awareness of young population regarding the EMF emission from video displaying units would markedly reduce screen time, thus, electromagnetic field pollution.

WHO established the International EMF Project in the year 1996 to provide an international platform for coordinated response towards EMF issues. However, International Commission on Non-Ionizing Radiation Protection (ICNIRP) aided by Institute of Electrical and Electronics Engineer (IEEE) puts up the guidelines regarding the exposure limits of EMF in residential and occupational fields. They do the research regarding the EMF and its importance in environment and present their analysed information to WHO for making guidelines and decisions regarding EMF. Though WHO and its auxiliary organisations have repeatedly told that the effect is not detrimental to health, but it didn't satisfy a large number of researchers, who have argued that only short term effects had been taken into consideration in the epidemiological studies and not the long term and non-thermal effects. WHO also issued a risk-assessment monograph EHC (Environmental Health Criteria) for EMF but a group of researchers from Karolinska University reported that the committee presiding over the EHC risk-assessment study mostly comprised of people who are from ICNIRP and IEEE itself and so can be biased.<sup>22</sup>

### CONCLUSION

There is no denying that the existing research works are pointing towards greater risk of adverse health effects ranging from irritability and sleep disturbance to paralysis and cancers. Therefore, the need of the hour is undertaking various preventive measures in order to minimize the exposure in the occupational as well as non-occupational settings. There should be Mass media effort to generate awareness about the possible health impacts of EMF, particularly focusing on young population and proper legislative measures should be taken to minimize EMF exposure at occupational settings. In long run for overall benefit and sustainable development we should start searching option to substitute the contemporary technologies with ones having favourable benefit-risk ratio.

## REFERENCES

1. Wertheimer N, Leeper ED. Electrical wiring configurations and childhood cancer. *Am J Epidemiol.* 1979;109(3):273-84.
2. World Health Organization. Electromagnetic fields and public health: electromagnetic hypersensitivity [Internet]. World Health Organization; 2005 [cited Apr 12, 2020]. Available from: <https://www.who.int/peh-emf/publications/facts/fs296/en/>
3. Fang Q, Mahmoud SS, Yan J, Li H. An investigation on the effect of extremely low frequency pulsed electromagnetic fields on human electrocardiograms (ECGs). *Int J Environ Res Public Health.* 2016;13(11):1171.
4. Balamuralikrishnan B, Balachandar V, Kumar SS, Stalin N, Varsha P, Devi SM et al. Evaluation of chromosomal alteration in electrical workers occupationally exposed to low frequency of electromagnetic field (EMFs) in Coimbatore population, India. *Asian Pac J Cancer Prev.* 2012;13(6), 2961-6.
5. Lasalvia M, Scrima R, Perna G, Piccoli C, Capitanio N, Biagi PF, et al. Exposure to 1.8 GHz electromagnetic fields affects morphology, DNA-related Raman spectra and mitochondrial functions in human lympho-monocytes. *PloS one.* 2018;13(6):e0198892.
6. Carlberg M, Hardell L. Evaluation of mobile phone and cordless phone use and glioma risk using the Bradford Hill viewpoints from 1965 on association or causation. *BioMed research international.* 2017;2017:9218486.
7. Kapri-Pardes E, Hanoch T, Maik-Rachline G, Murbach M, Bounds PL, Kuster N, et al. Activation of signaling cascades by weak extremely low frequency electromagnetic fields. *Cell. Physiol. Biochem.* 2017;43(4):1533-46.
8. Augner C, Hacker GW. Are people living next to mobile phone base stations more strained? Relationship of health concerns, self-estimated distance to base station, and psychological parameters. *Indian J Occup Environ Med.* 2009;13(3):141-5.
9. Xu S, Chen G, Chen C, Sun C, Zhang D, Murbach M, et al. Cell type-dependent induction of DNA damage by 1800 MHz radiofrequency electromagnetic fields does not result in significant cellular dysfunctions. *PloS one.* 2013;8(1):e54906.
10. Naarala J, Kolehmainen M, Juutilainen J. Electromagnetic fields, genomic instability and cancer: a systems biological view. *Genes.* 2019;10(6):479.
11. Wang H, Zhang X. Magnetic fields and reactive oxygen species. *Int J Mol Sci.* 2017;18(10):2175.
12. Medeiros LN, Sanchez TG. Tinnitus and cell phones: the role of electromagnetic radiofrequency radiation. *Braz J Otorhinolaryngol.* 2016;82(1):97-104.
13. Kesari KK, Agarwal A, Henkel R. Radiations and male fertility. *Reprod. Biol. Endocrinol.* 2018;16(1):118.
14. Singh R, Nath R, Mathur AK, Sharma RS. Effect of radiofrequency radiation on reproductive health. *Indian J Med Res.* 2018;148(Suppl): S92-9.
15. Pall, ML. Scientific evidence contradicts findings and assumptions of Canadian safety panel 6: icrowaves act through voltage-gated calcium channel activation to induce biological impacts at non-thermal levels, supporting a paradigm shift for microwave/ lower frequency electromagnetic field action. *Rev Environ Health.* 2015;30(2):99-116.
16. Teepen JC, van Dijk JA. Impact of high electromagnetic field levels on childhood leukemia incidence. *Int. J. Cancer.* 2012; 131(4):769-78.
17. Vijaylaxmi, Scarfi MR. International and national expert group evaluations: biological/health effects of radiofrequency fields. *Int J Environ Res Public Health.* 2014;11(9):9376-408.
18. Santini SJ, Cordone V, Falone S, Mijit M, Tatone C, Amicarelli F, et al. Role of mitochondria in the oxidative stress induced by electromagnetic fields: focus on reproductive systems. *Oxid Med Cell Longev.* 2018;2018:5076271.
19. Carlberg M, Hardell L. Evaluation of mobile phone and cordless phone use and glioma risk using the Bradford Hill viewpoints from 1965 on association or causation. *Biomed Res Int.* 2017;2017:9218486.
20. Reale M, Kamal MA, Patruno A, Costantini E, D'Angelo C, Pesce M, et al. Neuronal cellular responses to extremely low frequency electromagnetic field exposure: implications regarding oxidative stress and neurodegeneration. *PloS one.* 2014;9(8): e104973
21. Swerdlow AJ, Feychting M, Green AC, Kheifets L, Savitz DA. International Commission for Non-Ionizing Radiation Protection Standing Committee on Epidemiology. Mobile phones, brain tumors, and the interphone study: where are we now? *Environ. Health Perspect.* 2011;119(11):1534-8.
22. Hardell L. World Health Organisation, radiofrequency radiation and health – a hard nut to crack (Review). *Int J Oncol.* 2017; 51(2): 405-13.
23. Kane RC. A possible association between fetal/neonatal exposure to radiofrequency electromagnetic radiation and the increased incidence of autism spectrum disorders (ASD). *Med Hypotheses.* 2004;62(2):195-197.
24. Gunnarsson LG, Bodin L. Occupational exposures and neurodegenerative diseases—a systematic literature review and meta-analyses *Int J Environ Res Public Health.* 2019;16(3):337.
25. Subba SH, Mandelia C, Pathak V, Reddy D, Goel A, Tayal A, et al. Ringxiety and the mobile phone usage pattern among the students of a medical college in South India. *J Clin Diagn Res.* 2013;7(2):205-9.
26. Lewczuk B, Redlarski G, Zak A, Ziółkowska N, Przybylska-Gornowicz B, Krawczuk M. Influence of electric, magnetic, and electromagnetic fields on the circadian system: current stage of knowledge. *Biomed Res Int.* 2014; 2014:169459.
27. Jazi SD, Modolo J, Baker C, Villard S, Legros A. Effects of A 60 Hz Magnetic field of up to 50 milliTesla on human tremor and EEG: A pilot study. *Int J Environ Res Public Health.* 2017;14(12):1446.
28. Esmailzadeh S, Delavar MA, Aleyassin A, Gholamian SA, Ahmadi A. Exposure to Electromagnetic Fields of High Voltage Overhead Power Lines and Female Infertility. *Int J Occup Environ Med.* 2019;10(1):11-6.
29. Schnorr TM, Grajewski BA, Hornung RW, Thun MJ, Egeland GM, Murray WE, et al. Video display terminals and risk of spontaneous abortion. *N Engl J Med.* 1991; 324(11):727-33.
30. Luo Q, Jiang Y, Jin M, Xu J, Huang HF. Proteomic analysis on the alteration of protein expression in the early-stage placental villous tissue of electromagnetic fields associated with cell phone exposure. *Reprod Sci.* 2013;20(9):1055-61.
31. Dieudonné, M. Electromagnetic hypersensitivity: a critical review of explanatory hypotheses. *Environ Health.* 2020;19:48(2020).
32. INTERPHONE Study Group. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case-control study. *Int J Epidemiol.* 2010; 39(3):675-94.
33. Bortkiewicz A, Gadzicka E, Szymczak W. Mobile phone use and risk for intracranial tumors and salivary gland tumors-A meta-analysis. *Int J Occup Med Environ Health.* 2017;30(1):27-43.
34. Regel SJ, Achermann P. Cognitive performance measures in bioelectromagnetic research-critical evaluation and recommendations. *Environmental Health.* 2011;10(1):10.
35. Rööslä M, Lagorio S, Schoemaker MJ, Schüz J, Feychting M. Brain and salivary gland tumors and mobile phone use: evaluating the evidence from various epidemiological study designs. *Annu Rev of Public Health.* 2019;40:221-38.