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Electromagnetic hypersensitivity (EHS, microwave syndrome) – Review of mechanisms

Yael Stein (MD)[a,b,*], Iris G. Udasin (MD)[c]

[a] Pain Clinic, Department of Anesthesiology and Critical Care Medicine, Hebrew University-Hadassah Medical Center, Jerusalem, Israel
[b] Electromagnetic Radiation Clinic, Hebrew University-Hadassah Medical Center, Jerusalem, Israel
[c] EOHSI Clinical Center, Rutgers University- School of Public Health, NJ, USA

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ABSTRACT

Electromagnetic hypersensitivity (EHS), known in the past as "Microwave syndrome", is a clinical syndrome characterized by the presence of a wide spectrum of non-specific multiple organ symptoms, typically including central nervous system symptoms, that occur following the patient's acute or chronic exposure to electromagnetic fields in the environment or in occupational settings. Numerous studies have shown biological effects at the cellular level of electromagnetic fields (EMF) at magnetic (ELF) and radio-frequency (RF) frequencies in extremely low intensities. Many of the mechanisms described for Multiple Chemical Sensitivity (MCS) apply with modification to EHS. Repeated exposures result in sensitization and consequent enhancement of response. Many hypersensitive patients appear to have impaired detoxification systems that become overloaded by excessive oxidative stress. EMF can induce changes in calcium signaling cascades, significant activation of free radical processes and overproduction of reactive oxygen species (ROS) in living cells as well as altered neurological and cognitive functions and disruption of the blood-brain barrier. Magnetite crystals absorbed from combustion air pollution could have an important role in brain effects of EMF. Autonomic nervous system effects of EMF could also be expressed as symptoms in the cardiovascular system. Other common effects of EMF include effects on skin, microvasculature, immune and hematologic systems. It is concluded that the mechanisms underlying the symptoms of EHS are biologically plausible and that many organic physiologic responses occur following EMF exposure. Patients can have neurologic, neuro-hormonal and neuro-psychiatric symptoms following exposure to EMF as a consequence of neural damage and over-sensitized neural responses. More relevant diagnostic tests for EHS should be developed. Exposure limits should be lowered to safeguard against biologic effects of EMF. Spread of local and global wireless networks should be decreased, and safer wired networks should be used instead of wireless, to protect susceptible members of the public. Public places should be made accessible for electro-hypersensitive individuals.

1. Background and introduction

Electromagnetic hypersensitivity (EHS), known in the past as "Microwave syndrome", is a clinical condition characterized by a broad spectrum of non-specific multiple organ systems that typically occur after a person's exposure to electromagnetic fields (EMF) from the environment. Numerous studies have shown biological effects at the cellular level of electromagnetic fields (EMF) at magnetic (ELF) and radio-frequency (RF) frequencies in extremely low intensities. Sensitivity to EMF, a systemic human response to chronic low intensity radio frequency (RF) exposure, was first reported by Soviet medical researchers in the 1950's, who named it "neurotic syndrome" (Johnson Liakouris, 1998; Silverman, 1973). The symptoms are similar to those reported by patients with multiple chemical sensitivity (MCS) and include central nervous system symptoms, including headache, fatigue, stress, sleep disturbance, "brain fog", short term memory disturbances, irritability, emotional lability and anxiety. Other symptoms that are often experienced by patients include nausea, chest pain, palpitations, shortness of breath, muscle aches, reduced libido, decreased appetite, and skin reactions (Pollack and Healer, 1967; Dodge, 1969; Glaser, 1972; Irvine, 2005; Mild et al., 2004; Eltiti et al., 2007; McCarty et al., 2011; Baliatsas et al., 2012; Havas, 2013). The clinical syndrome was named "idiopathic environmental intolerance to electromagnetic fields" by the World Health Organization at its 2004 Prague workshop. In Sweden, "Electromagnetic Hypersensitivity" or EHS is an officially recognized functional impairment (Johansson, 2006).

* Corresponding author. Pain Clinic, Department of Anesthesiology and Critical Care Medicine, Hebrew University-Hadassah Medical Center, Jerusalem, Israel.
E-mail address: yael.stein1@mail.huji.ac.il (Y. Stein).

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The United States government issued reports in the 1970's and 1980's addressing occupational exposure to EMF. Workers with increased duration of exposure to EMF experienced headache, sleep disturbance, moodiness, depression, memory impairment, increased perspiration and decreased libido (Dwyer and Leeper, 1978). Lerner (1980) followed a cohort of 1300 workers. Those with relatively low-level EMF exposure experienced a doubling of neuropsychiatric symptoms. Those workers who were exposed to higher levels of EMF experienced a tripling of neuropsychiatric symptoms (Pall, 2016). Workers who installed wireless smart meters outside homes report increase in insomnia, tinnitus, pressure in the head, and difficulty concentrating which increased in severity with increased exposure (Conrad, 2013).

Bergqvist et al. (1997) described three stages in development of EHS: in the first stage transient symptoms appear and decline, in the second stage the symptoms persist with increased duration or intensity, or increased number of symptoms and in the third stage disabling neurologic symptoms are triggered after even low levels of exposure to EMF. The Austrian Medical Association (2012) recognizes sleep problems, muscle and joint issues, headaches, difficulty concentrating, memory problems, as well as tinnitus and sensation of pressure within the ears. Hutter et al. (2010) noted tinnitus in a subgroup of cell phone users that used their phone on the ipsilateral side for 4 years and longer (OR 1.95; CI 1.00–3.8). Use of cell phones for more than 60 min per day over at least four years has been associated with subjective symptoms of ear warmth and tinnitus, which is thought to be associated with ear damage (Panda et al., 2010).

The most common complaint of people with exposure to EMF form cellphones is headache (Yakymenko et al., 2011, 2015). showed an increase in prevalence of headaches and earaches (63.6%) in cell phone users who talk over 3 h per day, compared to 20% in subjects who spoke on cell phones for less than 15 min per day. Szyjkowska et al. (2014) reported similar findings where 62% of adult cell phone users reported headaches while speaking on a cell phone. A study of Indian medical students found that 22% of cell phone users reported headaches and 91% had ear aches if they were talking on a cell phone more than 2 h per day. Headaches and ear aches were also experienced in this cohort if they were using cell phones for social media, games, and video (Datta et al., 2016). An intervention study performed in Egypt showed that prevalence of headaches, decreased concentration and insomnia in students improved after decreased use of cell phones (Mohamed et al., 2014). A study in China showed that children between the ages of 9–12 owning a cell phone for more than a year doubled the prevalence of headache and sleep disorders (Zheng et al., 2015).

Belpomme and Irigaray have compiled a database of more than 2000 self-reported cases of EHS and/or Multiple Chemical Sensitivity (MCS) patients. The authors list the symptoms reported by their patients: "*headache, tinnitus, hyperacusis, dizziness, balance disorder, superficial and/ordeep sensibility abnormalities, fibromyalgia, vegetative nerve dysfunction, and reduced cognitivecapability, including immediate memory loss, attention–concentration deficiency, and eventuallytempo-spatial confusion. These symptoms were associated with chronic insomnia, fatigue, anddepressive tendency, in addition to emotional lability and sometimes irritability.*"

Each patient's specific symptom profile was repeatedly and consistently reported by the patient upon exposure to EMF sources, even of weak intensity, and regressed or gradually disappeared after they left these presumed sources.

The symptoms described above are largely self-reported but cause significant discomfort and potential disability in both adults and children. The present review discusses sources of exposure and measurements of exposure as well as objective measurements/clinical testing to explain symptoms and health effects experienced in patients who are exposed to EMF.

2. Exposure

Exposure to EMF has been described in 2008–9 as between 10 and 15 times higher than the earth's natural magnetic field (Röösli, 2008; Nittby et al., 2009). Specifically around the 1 GHz frequency band, exposures have risen by approximally 10^{18} times natural levels (Bandara and Carpenter, 2018). In 2010, it was estimated that more than 2 billion people use cell phones worldwide (Soffritti, 2010). The electromagnetic fields that people are potentially exposed to are generated by a variety of devices that are present in the environment or devices used by people including cell phones. Examples of artificial EMFs in the Radio Frequency (RF) range in the environment include mobile phones, antennas, and base stations (2G, 3G, 4G technology), and specific telecommunications systems and devices including Global system for mobile (GSM), universal mobile telecommunications systems, long term evolution, microwave radio lines, standard digital enhanced cordless telephony, cordless phones, laptops, tablets, e-readers, wireless internet networks (Wi-Fi), Wireless local area network (LAN), video display units, radio, television, wireless video game consoles, and wireless meters of water and gas usage. 5G technology is currently under development and will potentially add to exposure. Exposure sources of lower frequency electromagnetic fields include high tension power lines, electrical installations, fluorescent lamps, and photocopy machines (Kaszuba-Zwoińska et al., 2015; De Luca et al., 2014; Belyaev et al., 2016).

3. Physiologic evidence of health effects

Several studies cite abnormalities in neuropsychiatric testing in patients who report neuropsychiatric symptoms after exposure. Reeves (2000) reported on 34 US Air Force personnel who were exposed to RF at intensities greater than permissible exposure limits. The young men reported acute neurologic symptoms after exposure and standardized neuropsychiatric testing indicated that two thirds of the subjects exhibited findings consistent with antisocial personality, mild organic brain syndrome, anxiety, and tendency towards somatization (Carpenter, 2015).

Other studies indicate changes in cerebral blood flow and brain glucose metabolism which can be demonstrated using positron emission tomography (PET) imaging (Volkow et al., 2011). Volkow was able to demonstrate in healthy human volunteers that a 50-min cell phone conversation was associated with increased brain metabolism in the brain lesion closest to the cell phone antenna, compared with no exposure. Several studies (Haarala et al., 2003; Huber et al., 2002, 2005) showed changes in findings on PET imaging of the brain. Huber et al. (2005) was able to show that if the cell phone is further from the ear there are decreased changes in cerebral blood flow.

Belpomme et al. (2015) looked for specific brain pathologic alterations in 727 EHS and MCS patients. Regular cerebral MRI and carotid ultrasounds were generally normal in the patients examined. The authors then measured the brain blood flow in the temporal lobes of both cerebral hemispheres of the patients. This was done by using echo doppler and measuring pulsations in the brain. The author found that in comparison to normal subjects, cerebral pulsatility was decreased in MCS and EHS patients, and that the pulsatility was almost abolished in the temporal lobes. While these measurements may be non-specific, they do represent potential changes in brain function in these patients. In their updated paper, Belpomme and Irigaray reproduced their findings using ultrasonic cerebral tomosphygmography and transcranial Doppler ultrasonography in a much larger database of over 2000 patients (Belpomme and Irigaray, 2020). They summarized that many of the patients have a defect in the middle cerebral artery hemodynamics, and localized a *tissue pulsometric index deficiency* in the capsulo-thalamic area of the temporal lobes. The authors suggest this localized finding demonstrates objective evidence of biological involvement of the limbic system and the thalamus.

Belpomme and Irigaray demonstrated low-grade inflammation EHS patients. Hypersensitive C reactive protein (hs-CRP) was found to be increased in 12–15% of the patients, histamine in 30-40%, immunoglobulin E (IgE) in 20–25% patients with no proven allergy, and heat-shock protein 27 (HSP 27) and HSP-70 in 12–30% of the patients. Autoantibodies against O-myelin were detected in the peripheral blood in about 20% of the patients. An increase in S100B protein was seen in 15–20% of the patients and an increase in nitrosative stress-relatednitrotyrosine (NTT) in 8–30%. The authors concluded that the findings suggest an *autoimmune response against the white matter of the nervous system* in these patients. 79% of EHS patients presented with an increase in at least one of the studied oxidative/nitrosative stress-related biomarkers in their peripheral blood: thiobarbituric acid reactive substances (TBARS), oxidized glutathione (GSSG), and/or NTT oxidative stress biomarkers. 15% of the patients had all 3 biomarkers, 21% had two of the biomarkers and an additional 43% had only one biomarker. Levels of 24-h urine 6-hydroxymelatonin (6-OHMS, a melatonin metabolite) /creatinine ratio was normal or significantly decreased in 88% of cases, and significantly increased in 12% of the patients. The authors suggested that the low levels could result from utilization of melatonin as a free radical scavenger.

There is some evidence of objective cardiovascular changes after exposure to EMF. Havas (2013) and Tuengler and von Klitzing (2013) reviewed the literature and cited occupational studies of workers with excess exposure to EMF who had higher frequency of resting and 24-h ECG abnormalities and an excess of ventricular premature beats.

4. Mechanisms

Many of the mechanisms described for Multiple Chemical Sensitivity (MCS) apply with modification to EHS. Repeated exposures result in sensitization and consequent enhancement of response (Overstreet, 2001; Latremoliere and Woolf, 2009; Molot, 2013; Sage, 2015). Many hypersensitive patients appear to have impaired detoxification systems that become overloaded by excessive oxidative stress (Korkina, 2009; De Luca et al., 2014). Patients can have neurologic, neuro-hormonal and neuro-psychiatric symptoms following exposure to EMF as a consequence of neural damage and over-sensitized neural responses (Dwyer and Leeper, 1978; Pall, 2016). EMF can induce changes in calcium signaling cascades (Liboff, 1984; Blackman et al., 1985; Smith et al., 1987; Pall, 2013, 2015), significant activation of free radical processes and overproduction of reactive oxygen species (ROS) in living cells (Irmak et al., 2002; Zmyslony et al., 2004; Friedman et al., 2007; Blank and Goodman, 2009; De Iuliis et al., 2009; Georgiou, 2010; Avci et al., 2012; Jing et al., 2012; Bilgici et al., 2013; Burlaka et al., 2013) as well as altered neurological and cognitive functions (Frey, 1961; Thomas et al., 1986; Carrubba et al., 2007; Nittby et al., 2009; Xu et al., 2010; Molot, 2013; Yakymenko et al., 2016; Pall, 2016; Kim et al., 2017) and disruption of the blood-brain barrier (Salford et al., 2008; Nittby et al., 2009). Magnetite crystals absorbed from combustion air pollution could have an important role in brain effects of EMF (Maher et al., 2016).

5. Conclusion

In the modern world, exposure to electromagnetic radiation has become inescapable. There are many people who develop adverse health effects as a result of exposure to EMF. This review of the literature included numerous self-reported neurologic and neuropsychiatric symptoms which have a temporal relationship to EMF exposures. Further studies suggest that EMF exposure may be associated with changes in cerebral blood flow which correspond to abnormalities on PET scan of the brain. Some of the researchers have even localized the brain abnormalities to the temporal lobe, thought to be the closest site of exposure to cell phones. Because of the widespread use of EMF technology, it is difficult to avoid exposure.

Clearly, many individuals have sensitivity to EMF which decreases the quality of life and often leads to disability. Further research needs to be done to address the safety of cell phones and to use safer access to internet, especially in schools where children are exposed for many hours. More relevant diagnostic tests for EHS should be developed. Exposure limits should be lowered to safeguard against biologic effects of EMF. Spread of local and global wireless networks should be decreased, and safer wired networks should be used instead of wireless, to protect susceptible members of the public. Public places should be made accessible for electrohypersensitive individuals.

Declaration of competing interest

The authors declare no conflict of interest.

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