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Exposure to Static and Extremely-Low Frequency Electromagnetic Fields and Cellular Free Radicals

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ABSTRACT

This paper summarizes studies on changes in cellular free radical activities from exposure to static and extremely-low frequency (ELF) electromagnetic fields (EMF), particularly magnetic fields. Changes in free radical activities, including levels of cellular reactive oxygen (ROS)/nitrogen (RNS) species and endogenous antioxidant enzymes and compounds that maintain physiological free radical concentrations in cells, is one of the most consistent effects of EMF exposure. These changes have been reported to affect many physiological functions such as DNA damage; immune response; inflammatory response; cell proliferation and differentiation; wound healing; neural electrical activities; and behavior. An important consideration is the effects of EMF-induced changes in free radicals on cell proliferation and differentiation. These cellular processes could affect cancer development and proper growth and development in organisms. On the other hand, they could cause selective killing of cancer cells, for instance, via the generation of the highly cytotoxic hydroxyl free radical by the Fenton Reaction. This provides a possibility of using these electromagnetic fields as a non-invasive and low side-effect cancer therapy. Static- and ELF-EMF probably play important roles in the evolution of living organisms. They are cues used in many critical survival functions, such as foraging, migration, and reproduction. Living organisms can detect and respond immediately to low environmental levels of these fields. Free radical processes are involved in some of these mechanisms. At this time, there is no credible hypothesis or mechanism that can adequately explain all the observed effects of static- and ELF-EMF on free radical processes. We are actually at the impasse that there are more questions than answers.

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Static and extremely-low frequency electromagnetic fields; free radicals; Fenton reaction; cell proliferation; evolution

Introduction

This is a review of the research on the effects on cellular free radicals after exposure to static- and extremely-low frequency (ELF, 0–300 Hz) non-ionizing electromagnetic field (EMF). In 1997, we first reported that melatonin, a potent antioxidant, and the spin-trap compound N-tert-butyl-alpha-phenylnitrone (that neutralizes free radicals) blocked a 60-Hz magnetic field-induced DNA strand break in cells of the rat brain (Lai and Singh 1997a, 1997b). Further experiment (Lai and Singh 2004) demonstrated similar inhibitory effects of Trolox (a vitamin E-analog anti-oxidant) and 7-nitroindazole (a nitric oxide synthase inhibitor). In addition, the effect could also be blocked by the iron chelator deferiprone suggesting the involvement of the iron-catalyzed Fenton Reaction that produces the potent cytotoxic hydroxyl free radical. These data indicated that the ELF magnetic field affected free radicals in cells leading to cellular molecular damages. There are now more than 200 papers published showing that static and ELF-EMF affect cellular free radical processes. A list of the papers is in the "supplementary material" included in the online version of this paper. There are rather strong indications that exposure to static- and ELF-EMF affects oxidative status in cells and animals. Many of the cellular oxidative and anti-oxidative components have been shown to be affected by the fields.

Effect on cellular free radical processes is probably the most consistent biological effect of non-ionizing electromagnetic fields (EMF). It has been reported in many different animal and plant species after exposure to EMF from static to radiofrequency (see Yakymenko et al. (2016) and a 2017-update in the "oxidative effects of ELF-EMF and radiofrequency radiation (RFR) section" in the Bioinitiative Report (2012)).

Free radicals

Reactive free radicals (mainly, reactive oxygen species (ROS) and reactive nitrogen species (RNS)) are produced as a result of cellular metabolism, particularly in the mitochondria. Reactive oxygen species (ROS) include mainly singlet oxygen, superoxide, peroxides,

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and hydroxy radical and reactive nitrogen species (RNS) including mainly peroxtnitrite, nitrogen dioxide, which are products of the reaction between nitric oxide and superoxide. Nitric oxide is generated in cell by nitric oxide synthases. Presence of free radicals in cells can lead to macromolecular damages (in DNA, proteins, and lipids), disturbance in cell functions, and cell death. Damage in DNA is a cause of cancer. Under normal conditions, free radical levels are kept in check by various inducible antioxidant enzymes including superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx). In instances, when there is an excessive increase in free radical production or a deficit in anti-oxidant capacity, oxidative/nitrosative stress results leading to cellular damage and functional deficits. However, free radicals also serve important cellular functions and are involved in cellular signaling cascades that govern normal cell functions and in immune defense against bacteria. They are also involved in cellular chemistry that triggers apoptosis. Thus, it is essential to keep free radicals at a critical physiological homeostatic level. Any disturbance could lead to detrimental biological consequences (cf. Pizzino et al. 2017; Valko et al. 2007).

Cellular free radical processes is a complex physiological mechanism. It involves feedbacks and compensatory responses of different cellular components to maintain homeostasis. EMF could disturb different components of the process leading to a cascade of changes. Since exposure to EMF leads to disturbance in free radical production and excessive presence of free radicals in cells can be considered as a stress, living organisms under chronic EMF exposure probably go through the three phases of the "general-adaptation-syndrome" of stress, i.e., alarm, resistance, and exhaustion phases (Selye 1951). Thus, the characteristic of the free-radical responses depends on how long exposure has been occurring. In addition, effects observed could depend on the cell type and organ studied; time when the changes were studied, and exposure conditions (such as intensity, cumulative duration of exposure, and characteristics of the field). Thus, it is not surprising that the changes described in the "supplementary material" show a complex pattern, i.e., changes are not always in the same direction. Research on the effects of static- and ELF-EMF is mainly on ROS. There are only few studies on RNS (~5%).

Effects of static and ELF EMF-induced changes in cellular free radical processes

Several papers reported changes in biochemistry, physiology, and general functions as a consequence of changes in cellular oxidative status resulting from exposure to static- and ELF-EMF. These include: DNA damage (Giorgi et al. 2017; Jajte et al. 2001; Koyama et al. 2008; Lai and Singh 1997a, 1997b; Lai and Singh 2004; Yokus et al. 2005, 2008); immune response (Akan et al., 2010; Kim et al. 2017); inflammatory response (Kim et al. 2017; Zhang et al. 2017); apoptosis (De Nicola et al. 2006; Ding et al. 2004; Garip and Akan 2010; Ghodbane et al. 2015; Koh et al. 2008; Solek et al. 2017; Wartenberg et al. 2008; Yang and Ye 2015); protein misfolding and generation of prions (Lian et al. 2018); cell proliferation and differentiation (Ehnert et al. 2017; Hajipour Verdam et al., 2018; Lee et al. 2010; Patruno et al. 2010; Song et al. 2018; Van Huizen et al. 2019; Wolf et al. 2005); rhythmic slow activity in hippocampal slices of the brain (Bawin et al. 1996); visual evoked potentials (Akpinar et al. 2012); auditory event-related potentials (Akpinar et al., 2016); visual and somatosensory evoked potentials (Akpınar et al. 2016); heart rate (Ciejka and Goraca 2009); wound healing (Glinka et al. 2013; Patruno et al. 2010, 2011); bone formation (Zhang et al. 2018); post-stroke recovery (Cichoń et al. 2017a, 2017b, 2018); hyperalgesia (Jeong et al. 2006); opioid-induced antinociception (Kavaliers et al. 1998); spatial memory and learning (Cui et al. 2012; Deng et al. 2013; Karimi et al. 2019); cognitive impairment (Duan et al. 2013); mismatch-negativity response (Kantar-Gok et al., 2014); depressive disorder (Ansari et al. 2016); anxiety-like behavior (Djordjevic et al. 2017); and obsessive compulsive disorder-like behavior (Salunke et al. 2014). However, in most of these studies, the cause–effect relationship was not well established. Do EMF-induced changes in oxidative status cause these effects? Or, are they effects of EMF caused by mechanisms unrelated to oxidative changes? One powerful proof of a free-radical effect is to establish whether an effect, e.g., DNA damage, could be blocked by antioxidants or pro-oxidants. An effect caused by a change in free radicals should be able to be blocked by antioxidants or pro-oxidants. There are several studies that employed this strategy (see "Supplementary material").

In most of the ELF-oxidative effects studies, the intensities used were relatively high (i.e., more than 0.1 mT) compared to ambient levels of static- and ELF-EMF (in μT levels) in the human environment. However, effects at high intensities could possibly occur in occupational exposure situations where the levels are relatively high. In addition, the exposure durations in most of these studies are short-term (from hours to several days), whereas environmental exposure is generally chronic. Can most of the research results applicable to real-life exposure situation? Do oxidative changes occur after exposure to ambient levels of static- and ELF-EMF?

Table 1. Free radical effects observed at low intensities of static and ELF-EMF.

	Effect observed	Exposure conditions
Bediz et al. (2006)	Oxidative changes in rat blood and brain	50 Hz; 5 μT
Belova et al. (2010)	Changes in ROS and activation of mouse peritoneal neutrophils	Continuous-wave (31 Hz) and pulsed (15 Hz); 74.7 μT
Budziosz et al. (2018)	Change in SOD activity in the rat brain	50 Hz; 4.4 pT
Calcabrini et al. (2017)	Increased ROS in human keratinocytes	50 Hz; 50 μT
Ehnert et al. (2017)	Changes in oxidative status and differentiation in human osteoblasts	16 Hz pulses; 6 – 282 μT
Fernie and Bird (2001)	Increase in oxidative stress in male American kestrels	50 Hz; 30 μT
Hajnorouzi et al. (2011)	Decreased SOD and Growth promotion of maize seedlings	Static and 10 KHz; 22 μT
Karimi et al. (2019)	Increases in total oxidant status and antioxidant activity and change in memory retention in rats	50 Hz; 1–2000 μT
Kesari et al. (2016)	Increase in superoxide in SH-SY5Y human neuroblastoma cells pretreated with menadione	50 Hz; 10 μT
Mannerling et al. (2010)	Increase in superoxide in k562 human leukemia cells	50 Hz; at or below 25 μT
Manikonda et al. (2014)	Oxidative stress in rat brain	50 Hz; 50 μT
Martino and Castello (2011)	Changes in proliferation and SOD in human umbilical vein endothelial cells	Static; 30 μT
Naarala et al. (2017)	Increase in superoxide in rat glioma C6 cells	Static and 50 Hz; 30 μT
Poniedzialek et al. (2013)	Change in ROS in human neutrophils	EMF tuned to calcium ion cyclotron frequency; 10 μT
Regoli et al. (2005)	Decrease in CAT in snail digestive gland	50 Hz; 2.88 μT
Sharifian et al. (2009)	Decreases in SOD and GPx in human serum and red blood cells	50 Hz; 8.8–84 μT
Van Huizen et al. (2019)	Changes in ROS and regeneration in planarian	Static; 100 μT
Zhang et al. (2018)	Changes in nitric oxide activity in bone monocytes	50 Hz; 0.5 μT
Zmyslony et al. (2004)	Decrease in ROS in rat lymphocytes stimulated by $FeCl_2$	50 Hz; 40 μT

There are studies that showed effects on free radical processes at low static- or ELF-EMF intensities (at low μT levels). They are listed in Table 1. Furthermore, related to this is a paper by Kapri-Pardes et al. (2017) showing effects on cellular signal cascades in eight cell lines exposed to ELF-EMF at 0.15 μT at a similar level that has been suspected to cause childhood leukemia. Though the authors did not investigate the oxidative status of their cells, they concluded that the effects were mediated by NADP oxidase, an enzyme that can generate superoxide free radicals. In addition, similar to the finding of Kesari et al. (2016), Maes et al. (2016) also reported an increase in micronucleus formation in SH-SY5Y human neuroblastoma cells after exposure to a 50-Hz magnetic field at 10 μT, but without pretreatment with menadione as in the Kesari et al. (2016) study. Thus, disturbance of oxidative processes can possibly occur at ambient levels of static- and ELF-EMF (e.g., see ambient levels reported by Abuasbi et al. 2018a, 2018b; Bürgi A et al., 2017; Gourzoulidis et al. 2018; Ilonen et al. 2008; Lindgren et al. 2001; Yitzhak et al. 2012).

Effects of electric fields

A few words have to be said on exposure to electric fields. The exposure set-ups for the electric field are quite different from those of magnetic fields. There are at least 16 electric-field exposure studies on free radical processes: Akpinar et al. (2012, increase ROS in rat brain and retina; 2016, increased rat brain lipid peroxidation); Calota et al. (2006, decreased human serum ROS); Fitzsimmons et al. (2008, increased nitric oxide in human chondrocytes); Gok et al. (2016, increased lipid peroxidation in mouse brain and retina); Güler et al. (2008, increased lipid peroxidation in guinea pig liver); Güler et al. (2009a, no significant effect on guinea pig plasma protein carboxylation; 2009b, increased protein carboxylation in guinea pig lung); Harakawa et al. (2005, no significant effect on rat plasma); Kantar-Gok et al. (2014, increased rat brain protein carboxylation and lipid peroxidation); Luo et al. (2019, decreased insect antioxidant enzyme); Miliša et al. (2017, increased ROS in paramecium); Pakhomova et al. (2012, increased ROS in Jurkat cells); Türközer et al. (2008, no significant effect on guinea pig brain lipid peoxidation); Wartenberg et al. (2008, increased oral mucosa cancer cell SOD); and Wu et al. (2016, increased mouse liver SOD). In most studies, 50-Hz electric field at kV/m intensity (2–21.8 kV/m) and exposure time from hours to days were investigated. Most studies reported effects indicative of an increase in free radicals, e.g., increases in lipid peroxidation. Effects could occur at a very low level of electric field exposure. A study by Fitzsimmons et al. (2008) using a pulsed electric field at 0.00002 kV/m, reported an increase in nitric oxide after 30 min of exposure. Wartenberg et al. (2008) used a 0.004 kV/m DC-electric field and reported changes in activities in the antioxidant enzyme SOD. This is actually quite interesting. Since electric fields do not penetrate into cells, do electric and magnetic fields act on different mechanisms leading to changes in cellular free radical processes?

Static- and ELF-EMF, free radicals, and cell proliferation, viability, and differentiation

Free radicals can cause damages to cellular macromolecules (DNA, protein, and lipid). These damages can affect

cell functions. Mutation in DNA can lead to cancer development. However, too much damage to a cell can cause cell death. And death to precancerous and cancer cells decreases the incidence of cancer. This may be a possible non-invasive method for cancer prevention and treatment. It is, of course, not known how much EMF exposure is needed to push cancerous cell over the edge to death. It may depend on the type of cancer cell.

On the other hand, the death of cells that cannot reproduce and be replaced leads to dysfunction in organs. This is particularly true for nerve cells. The connection between EMF exposure and neurodegenerative diseases are still not yet well established. There are several recent studies indicating a possible correlation with Alzheimer's disease, amyotrophic lateral sclerosis, dementia, and motor dysfunctions (Gunnarsson and Bodin 2018; Huss et al. 2018; Jalilian et al. 2018; Koeman et al. 2017; Pedersen et al. 2017). There are, however, two interesting points that need to be pointed out. First, static- and ELF-EMF have been shown to reverse and improve cognitive performance in animal models of neurodegenerative disorders (Akbarnejad et al. 2018; Bobkova et al. 2018; Hu et al. 2016; Li et al. 2019; Liu et al. 2015; Sakhaie et al. 2017; Tasset et al. 2012). Can these be related to the effects of static- and ELF-EMF on protein folding and prion production (Lian et al., 2018) and induction of heat-shock proteins (Laramee et al. 2014; Zeni et al. 2017)? Second, there is an inverse correlation between cancer risk and Alzheimer's and Parkinson diseases (Poprac et al. 2017). An increase in cellular free radicals is a common factor of these diseases. This supports the notion that static- and ELF-EMF exposure can kill cancer cells and cause neurodegenerative diseases.

Harnessing cellular oxidative status using static and ELF-EMF could also be beneficial in the treatment of certain diseases. Several papers have suggested such possibilities including: improvement of immune responses (Akan et al. 2010; Belova et al. 2010; Frahm et al. 2006; Kim et al. 2017); treatment of osteoarthritis (De Mattei et al. 2003); attenuation of ischemic brain injury (Duong et al., 2016; Rauš Balind et al. 2014); increasing antioxidant properties in cells and tissues (Falone et al. 2016); treatment of myopathies (Vignola et al. 2012); wound healing and tissue regeneration (Glinka et al. 2013; Patruno et al. 2010, 2011; Van Huizen et al. 2019); cytoprotection (Osera et al. 2015, 2011); inducing differentiation of stem cells (Haghighat et al. 2017b, 2017a; Marycz et al. 2018; Park et al. 2013; Van Huizen et al. 2019); and protective effect on Huntington's disease (Tasset et al. 2012; Túnez et al. 2006). One interesting prospect is the use of static and ELF-EMF in the treatment of cancer. EMF can selectively kill cancer cells (Lai and Singh 2010). Many years ago, we (Lai and Singh 2004) speculated that cancer cells are more vulnerable to EMF than normal cells and that EMF kills cancer cells by free radical formation. Since it is much easier to produce ELF-EMF than RFR, and ELF-EMF gives a more uniform distribution and better tissue penetration that RFR, it is more advantageous to use ELF-EMF for cancer treatment. Let us look at the studies on static- and ELF-EMF exposure on free radicals and cell proliferation, differentiation, cell cycle, and cell death in cancer and normal cells, summarized in Table 2. These are important cellular processes that determine cancer development and treatment, growth, development, wound healing and regeneration in living organisms.

Several studies on cancer cells listed in Table 2 suggested a possible beneficial effect on cancer treatment under static- or ELF-EMF exposure by increasing apoptosis and decreasing proliferation and viability (Benassi et al. 2016; Ding et al. 2004; Errico Provenzano et al. 2018; Hajipour Verdom et al. 2018; Koh et al. 2008; Lai et al. 2016; Mannerling et al. 2010; Osara et al., 2011; Wartenberg et al. 2008; Yang and Ye 2015). However, others suggested a protective effect by decreasing apoptosis and increasing proliferation and viability that would allow cancer to grow faster (De Nicola et al. 2006; Falone et al. 2007, 2017; Garip and Akan 2010; Martinez et al., 2016; Osera et al. 2015; Song et al. 2018; Wolf et al. 2005), whereas no significant effect on cell viability and proliferation was reported by some studies (Consales et al. 2019; Morabito et al. 2010; Naarala et al. 2017; Pakhomova et al. 2012; Sadeghipour et al. 2012). Interestingly, A study (Ayşe et al. 2010) showed opposite effects depending on the duration of exposure. This reflects the discussion above on the dynamic of cellular free radical processes and their ability to compensate. Cell type probably plays a significant role. Cell-type-specific responses to ELF-EMF have been reported by Sullivan et al. (2011), Kesari et al. (2016), Koziorowska et al. (2018), Makinistian et al. (2019), and Wang et al. (2018). The conditions of exposure probably cause the diversity of responses, but the conditions of exposure described in the table do not reveal a clear pattern on how different exposure parameters affect cellular free radical processes and changes in cell proliferation, differentiation, and apoptosis. There is a slight tendency of an inverse relationship between free radical activity and cellular proliferation, i.e., an increase in free radicals causes a decrease in cell proliferation and vice versa. Also, increase in free radical activity tends to enhance apoptosis. This uncertainty is actually not surprising because, in each study, we are looking at only some components of the free radical processes and not the whole pattern of changes. Feedback and compensatory

Table 2. Static- and ELF-EMF-induced free radical changes and cell proliferation, differentiation, viability, and cell cycle in (a) cancer and (b) normal cells.

(a)	Cancer cell type	Exposure conditions	Oxidative effects	Effects observed
Ayşe et al. (2010)	K562 human leukemia cells	50 Hz MF, 5 mT, 1 h or 1 h/day for 4 days	Increased superoxide, effect disappeared at 2 h after exposure	Single exposure decreased differentiation, repeated exposure increased differentiation
Benassi et al. (2016)	SH-SY5Y human neuroblastoma cells	50-Hz MF, 1 mT, 6–72 h	Increased protein carboxylation	Enhanced neurotoxin-induced apoptosis
Consoles et al. (2019)	SH-SY5Y human neuroblastoma cells	50-Hz MF, 1 mT, 24–72 h	No change in superoxide and hydrogen peroxide	Decreased iron content and iron-gene expression in a mutant cell type; no effect on cell viability and proliferation
De Nicola et al. (2006)	U937 human lymphoma cells	Static MF, 0.6 mT, 2 h; 50-Hz MF 0.07–0.1 mT, 2 h	Increased ROS, decreased GSH	Reduced apoptosis
Ding et al. (2004)	HL-60 human leukemia cells	60-Hz MF, 5 mT, 24 h		Enhanced apoptotic effect of H_2O_2
Errico Provenzano et al. (2018)	Human acute promyelocytic leukemia NB4 cells	50-Hz MF, 2 mT, 8, 16, 24 h	Increased ROS	Decreased proliferation and enhanced differentiation of all-trans retinoic acid (ATRA)-treated NB4 cells
Falone et al. (2007)	SH-SY5Y human neuroblastoma cells	50-Hz MF, 1 mT, 96–192 h	No change in ROS, SOD and CAT; increased GST and GPx	Increased viability, no change in cell cycle and apoptosis; enhanced oxidative effects of H_2O_2
Falone et al. (2017)	SH-SY5Y human neuroblastoma cells	50-Hz MF, 0.1 or 1 mT, 5 and 10 days	Decreased protein carboxylation and DNA oxidation; Increased antioxidation defense and GPx activity	Increased proliferation and survival advantage of cells
Garip and Akan (2010)	K562 human leukemia cells	50-Hz MF, 1 mT, 3 h	Increased ROS	Decreased and increased apoptosis in untreated and H_2O_2-treated cells, respectively
Hajipour Verdom et al. (2018)	Human MCF-7 breast adenocarcinoma cells	Static magnetic field, 10 mT, 24 and 48 h	Increased ROS	Decreased viability and differentiation; synergistic with doxorubicin
Koh et al. (2008)	Human prostate cancer cells (DU145, PC3, and LNCaP)	60-Hz MF, 1 mT, 6, 24, 48, or 72 h	Increased hydrogen peroxide	Apoptosis and cell cycle arrest
Lai et al. (2016)	Human Molt-4 leukemia cells	0.2 Hz pulses, carrier frequency modulated 134 KHz field from radiofrequency ID chip, 1 h		Cell death blocked by the spin-trap compound N-tert-butyl-alpha-phenylnitrone and the iron chelator deferoxamine
Mannerling et al. (2010)	K562 human leukemia cells	50-Hz MF 0.025–0.1 mT, 1 h		Accumulation of cells in the G2 phase
Martínez et al. (2016)	Human NB69 neuroblastoma cells	50-Hz MF, 0.1 mT, 3-h on/3-h off for 24, 42, or 63 h, or continuously for 15–120 min		MF activated MAPK-p38 and ERK ½, increase in cell proliferation
Morabito et al. (2010)	Rat PC-12 pheochromocytoma cells	50-Hz MF, 0.1 or 1 mT, 30 min or 7 days	Increased ROS in 30 min 1 mT exposure; decreased CAT in 0.1 and 1 mT 30 min and increased catalase in 1 mT 7 day exposure	All effects were observed in undifferentiated and not in differentiated cells; no significant effect on cell proliferation
Naarala et al. (2017)	Rat C6 glioma cells	Nearly vertical 33 μT static MF plus a horizontal or vertical 50-Hz 30 μT MF, 2 h	Increased cytosolic superoxde in vertical static field horizontal 50-Hz MF (but not vertical 50-Hz MF)	Cell viability not affected.
Osera et al. (2011)	SH-SY5Y human neuroblastoma cells	72-Hz pulsed MF, 2 mT, 24 h	Increased SOD-1	Decreased cell proliferation with higher quiescence
Osera et al. (2015)	SH-SY5Y human neuroblastoma cells	72-Hz pulsed MF, 2 mT, 10 min for 4 times over 7 days or 72 h	Increased Mn-SOD	Increased protection against oxidative stress; pulsed MF prevented H_2O_2-induced decrease in cell number and HSP-70 expression
Pakhomova et al. (2012)	Jurkat cells derived from human T-cell leukemia	Nanosecond pulsed electric field (300 ns, 1–12 kV/cm)	Increased ROS proportional to pulsed number	No effect on U-937 cells (also derived from human lymphoma)
Sadeghipour et al. (2012)	Human T47D breast carcinoma cells	100 and 217 Hz pulsed EMF, 0.1 mT, 24–72 h	Increased ROS in 217-Hz 72 h exposure	No significant change in apoptosis
Song et al. (2018)	Human cervical cancer cells (HeLa)	60-Hz EMF, 6 mT, 72 h	Decreased ROS	Increased cell proliferation

(*Continued*)

Table 2. (Continued).

(a)	Cancer cell type	Exposure conditions	Oxidative effects	Effects observed
Wartenberg et al. (2008)	Human UM-SCC-14-C oral mucosa cancer cells	DC EF, 4 V/m, 24 h	Increased Cu/Zn SOD, decreased GSH, no change in CAT	Increased apoptosis and decreased cell proliferation
Wolf et al. (2005)	Human HL-60 leukemia cells	50-Hz MF, 0.5–1 mT, 24–72 h	Increased DNA oxidative damage, increased ROS in Rat-1 fibroblasts	Dose-dependent increase in cell proliferation
Yang and Ye (2015)	Human osteosarcoma MG-63 cells	50-Hz EMF, 1 mT, 1, 2 or 3 h	Increased ROS	Decreased viability and cell growth, increased apoptosis
(b)	Type of normal cells	Exposure conditions	Oxidative effects	Effects observed
Di Loreto et al. (2009)	Rat cortical neurons	50-Hz MF, 0.1 or 1 mT, 7 days	No effect on lipid peroxidation, total ROS, and GSH	Increased cell viability, decreased apoptosis
Ehnert et al. (2017)	Human osteoblasts	Pulsed EMF, 16-Hz, 6–282 μT; 7 min or 7min/day (>3 days)	Increased ROS after single exposure, decreased after repeated exposure; increased GPX3, SOD2, CAT, GSR	EMF promoted osteoblast differentiation
Emre et al. (2011)	Wistar rat in vivo, liver	Pulsed EMF (0.5 ms rise time, 9.5 ms fall time) EF 0.6 V/m, MF 1.5 mT, each frequency train of 1 Hz, 10 Hz, 20 Hz and 40 Hz was given for 4-min and with 1-min interval between each frequency (together 20 min.); on each day, three exposure cycles performed (1 h), 1 h per day for 30 days	Increased lipid peroxidation, increased SOD	No effect on apotosis, decreased necrosis
Feng et al. (2016)	Human amniotic epithelial cells	50-Hz MF, 0.2–2 mT, 30, 60, 120 min	Increased mitochondrial ROS	activation of Akt and anti-apoptotic effect
Ghodbane et al. (2015)	Wistar male rat in vivo, brain and liver	Static MF, 128 mT, 1 h/day, 5 days	No effect on lipid peroxidation, increased CAT in liver	Increased apoptosis in liver through a mitochondrial caspase-independent pathway
Hajipour Verdom et al. (2018)	Human HFF normal fibroblasts	Static MF, 10 mT, 24 and 48 h	Increased ROS and GSH	Decreased viability and differentiation
Hu et al. (2016)	Hippocampus of exposed 3xTg AD mice	50-Hz MF, 0.5 mT, 20 h/day for 3 months	Decreased ROS and molecules involved in oxidative stress	Decreased apoptosis
Mohammadi et al. (2018)	Tobacco cells	Static Magnetic field, 0.2 mT, 24 h	↑ H_2O_2, ↑ NO	Delayed G1-S transition, increased cyclic nucleotides
Patruno et al. (2010)	Human epidermal keratinocyte cell HaCaT	50-Hz MF, 1 mT, 3, 18, 48 h	Decreased superoxide, increased nitric oxide and nitric oxide synthase, decreased CAT	Increased cell proliferation
Romeo et al. (2016)	Human fetal lung fibroblast	Static magnetic field, 370 mT, 1 h/day for 4 days	No change in ROS	No effect on viability, DNA damage and apoptosis
Solek et al. (2017)	Mouse spermatogenic cell lines	2, 50, 120 Hz pulsed (1 sec on/1 sec off) and continuous-wave EMF, 2.5–8 mT, 2 h	Increased superoxide and nitric oxide	Cell cycle arrest and apoptosis
Song et al. (2018)	Human fetal lung fibroblasts (IMR-90)	60-Hz EMF, 6 mT, 72 h	Decreased ROS	Increased cell proliferation
Van Huizen et al. (2019)	Schmidtea mediterranea (planarian), regeneration after amputation	Static magnetic field;100–400 μT and 500 μT; 12, 24 or 48 h	↓ ROS after 100–400 μT and ↑ ROS after 500 μT exposure	Decreased regeneration at 100–400 μT, increased at 500 μT; increased ROS promotes stem cell proliferation and differentiation
Zhang et al. (2018)	RAW264.7 bone monocytes	Static MF, 500 nT, 0.2 T, 16 T; 12 h to 4 days	Increased NO (16 T); decreased NO (500 nT and 0.2 T); increased NOS (16 T) decreased NOS (500 nT and 0.2 T)	Nitric oxide mediates SMF effects on osteoclast formation; effect depends on intensity of MF- decreased at 16T and increased at 500 nT and 0.2 T

mechanisms further complicate the picture. It is like the predicament of the "blind men and the elephant": "each was partly in the right, and all were in the wrong!" Thus, it is imperative to understand the conditions under which static- and ELF-EMF could cause a consistent increase/decrease in free radical activity in cells.

However, one must also keep in mind that free radical is by no means the only mechanism by which static- and ELF-EMF affect cell proliferation and viability. Other mechanisms could be involved, e.g., activation of the ERK1/2 signaling pathway (Qiu et al. 2019); and heat shock proteins (Zeni et al. 2017).

Magnetic field and the Fenton reaction

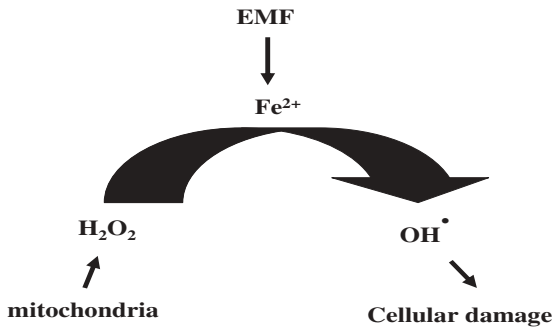
The iron-involved Fenton reaction may play a role in the generation of free radicals after EMF exposure. In previous research, we (Lai and Singh 1997a) found that an acute (2 hr) exposure to a 60-Hz magnetic field caused DNA single and double strand breaks in brain cells of rats. The effects were mediated by free radicals (Lai and Singh 1997b). Data also showed that the effects involved iron, since they can be blocked by pre-treating rats before magnetic-field exposure with the iron chelator deferriprone. More recently, we found that pulsed ELF-EMF field could also kill human Molt-4 leukemia cells via an iron-dependent free radical process (Lai et al. 2016).

Iron plays a vital role in cell growth, e.g., in energy metabolism and DNA synthesis. For DNA synthesis, riboses are converted into deoxyriboses, a component of the DNA molecule, by the enzyme ribonucleotide reductase, of which iron is a cofactor. Immediately before cell division, iron is taken up into cells. In vertebrates, a cellular iron transport system involves a specific interaction between the iron-binding protein transferrin in the extracellular fluid and cell surface transferrin receptors that results in a facilitated transport of iron across the cell membrane via endocytosis (Trowbridge et al. 1984). Due to their rapid rate of division, most cancer cells have high rates of iron intake (Karin and Mintz 1981) and express a much higher cell surface concentration of transferrin receptors (May and Cuatrecasas 1985) than normal cells. In general, the aggressiveness of a tumor is positively correlated with cell surface transferrin receptor concentration of its cells. For example, breast cancer cells have 5–15 times more transferrin receptors on their cell surface than normal breast cells (Reizenstein 1991), and they take up more iron than normal breast cells (Shterman et al. 1991). This is basically true in many different types of cancer cells.

Since cellular responses to magnetic fields involve an iron-dependent process, we hypothesize that cancer cells are more responsible to magnetic fields than normal cells. The more potent hydroxyl free radicals are formed by the Fenton Reaction from hydrogen peroxide produced mainly in the mitochondria and in the cytoplasm by superoxide dismutase (SOD) (Figure 1).

Indeed, there are studies indicating that cancer cells are more responsive to EMF than normal cells (Crocetti et al. 2013; Curley et al. 2014; Kamalipooya et al. 2017; Lai and Singh 2010; Morotomi-Yano et al. 2014; Tofani et al. 2001; Zimmerman et al. 2012). Various studies demonstrated that iron chelators blocked the effect of ELF-EMF on oxidative processes (Calcabrini et al. 2017; Lai et al. 2016; Lai and Singh 2004). In addition, static- and ELF-EMF have been shown to affect iron metabolism and iron-related gene expressions in cells (Consales et al. 2019; Dey et al. 2017; Fitak et al. 2017; Hajnorouzi et al. 2011; Lee et al. 2015; Shokrollahi et al. 2018). One can speculate that magnetic field causes a type of cell death know as ferroptosis, which can be blocked by iron chelators and lipid-soluble antioxidants and is being explored as a mean for cancer therapy (Shen et al. 2018; Wang et al. 2018b).

This mechanism provides a non-invasive mean of using ELF-EMF to selectively kill cancer cells (thus less side effects) by taking advantage of a fundamental property of cancer cells, i.e., high uptake of iron and increased the production of cytotoxic free radicals. This also led to the development, by us, a group of anticancer compounds that produce carbon-based free



The Fenton Reaction

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^{\bullet} + OH$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HOO^{\bullet} + H^{+}$$

Figure 1. The Fenton Reaction and effect of EMF exposure that enhances the conversion of hydrogen peroxide into hydroxyl radical catalyzed by a transition metal such as iron. Ferrous iron (Fe^{2+}) is converted into ferric iron (Fe^{3+}) in the formation of hydroxyl radical (OH) from hydrogen peroxide (H_2O_2). Ferric iron is converted back to the ferrous form by reacting with hydrogen peroxide.

radicals in the presence of iron (Lai et al. 2013). These compounds have been shown to be very selective and effective in killing many types of cancer cells. In addition, the concept of the Fenton Reaction also led to the idea of using ELF-MF for treatment of malaria (Feagin et al. 1999; Lai and Singh 2010).

The evolutionary aspects of static- and ELF-EMF in nature and free radicals

For millions of years, living organisms evolved in the presence of environmental static geomagnetic field and natural extremely low frequency electromagnetic fields, such as the lightning-generated Schumann Resonance. It is not surprising that these fields can play important roles in the survival of living organisms, e.g., in food foraging, directional cues, and reproduction. Living organisms are very sensitive and responsive to low levels of these EMFs. This has been shown in many animal species and affect various biological functions, e.g., exploratory behavior in rodents (Malewski et al. 2018); body alignment of dogs (Hart et al. 2013a); magnetic alignment in carps (Hart et al. 2012); landing direction of water birds (Hart et al. 2013b); orientation of grazing and resting cattle and deer (Begall et al. 2008); and cardiovascular and brain activities in humans (Pishchalnikov et al. 2019; Wang et al. 2019). Some animals can differentiate north and south poles of a magnetic field (known as polarity compass) (Begall et al. 2008; Hart et al. 2012, 2013b, 2013a; Malkemper et al. 2015). Another function-related reproduction is the "natal homing behavior", i.e., an animal returns to its birthplace to reproduce, in some animal species. It is observed in sea turtle (Brothers and Lohmann 2015); eel (Naisbett-Jones et al. 2017); and salmon (Putman et al. 2014b). Apparently, newborns of these animals are imprinted with the memory of the intensity and inclination angle of the local geomagnetic field. This information will later be used to locate their place of birth. All these traits confer some survival competitiveness to the organisms.

In order for an environmental entity to affect the functions of an organism, the following criteria have to be met. First, the organism should be able to detect the entity. Second, the level of the entity should be similar to those in the normal ambient environment. Third, the organism must have response mechanisms tuned to certain parameters of the entity to allow immediate detection of the presence and changes of the entity. Immediate detection and response to the entity are essential for the survival of the organism.

For the detection of changes in static- and ELF-EMF in the environment, several mechanisms have been evolved. Some organisms evolved special organs (receptors) to detect environmental EMF. For example, the platypus has thousands of electric sensors on its bill skin. Using these electroreceptors, in interaction with another type of sensor the mechanoreceptor, the monotreme platypus can detect an electric field of 20 μV/cm (Manger and Pettigrew 1996), which is similar to that produced by the muscles of a shrimp. The information is processed by the somatosensory cortex of the platypus to fix the location of the prey. This type of electroreception is common in all three species of monotremes and short bill echidna. Electric fish (Elasmobranch) emits EMF that covers a distance of several centimeters (Montgomery and Bodznick 1999; von der Emde 1999). Again, this allows the location of a potential prey by comparing its electrical properties with the vicinity. Their electroreceptors have been shown to detect a field of 5 nV/cm. These EMF sensing mechanisms are highly sensitive and efficient.

Two other mechanisms have been proposed to account for electroreception: magnetite involved in iron-oxidation and radical pair production in certain cellular molecules. In both cases, the generation of reactive oxidative species is involved. The radical-pair reaction hypothesis and conversion of the form of radicals (singlet-triplet interconversion) in a group of flavoproteins known as cryptochromes (Hore and Mouritsen 2016) in animal species have been intensively studied. There are reports of the presence of cryptochromes in plants, which may be responsible for the effect of EMF on plant growth (Ahmad et al. 2007; Mohammadi et al. 2018). A comprehensible description of this topic is beyond the scope of this paper and the expertise of this author. Readers are referred to several papers on the topic: Barnes and Greenebaum (2015); Binhi and Prato (2017); Galler et al. (2005); Dodson et al. (2013); Hore (2019); Hore and Mouritsen (2016); Kirschvink et al. (2001); Landler and Keays (2018); Sheppard et al. (2017); and Sherrard et al. (2018).

Thus, the mechanisms described above, electro-receptors, magnetites, and radical-pair, enable living organisms to immediately detect the presence and changes in environmental electromagnetic fields of very low intensity. An effect that could have dire consequences on species survival is that man-made EMFs, with ubiquitous presence in the recent environment, could disrupt the natural responses to nature static- and ELF-EMF. Disruption of directional senses in insects has been reported (Shepherd et al. 2018). Polarity compass also can be disturbed by man-made EMF (Burda etal. 2009; Malkemper et al. 2015; Putman et al. 2014a). A study by Engels et al. (2014) showed that magnetic noise (at 2 KHz – 9 MHz, i. e., within the range of AM radio transmission) could disrupt magnetic compass orientation in migratory European robins. The disruption can occur at a very low noise level of 0.01 V/m (0.0000265 μW/cm^2). Similar effects of RFR interference on magnetoreception have

also been reported in a night migratory songbird (Aher et al. 2016) and European robin (Wiltschko et al. 2015).

Electro-hypersensitivity in humans (Baliatsas et al. 2012) also showed an instantaneous response to EMF and at low intensities. One wonders whether the underlying mechanisms of electro-hypersensitivity are related to the processes described above. It may be the remnant of a primordial evolutional response of humans to static- and ELF-EMF in the environment. Free radicals may play a role. There is a report of increased oxidative stress in electro-hypersensitivity self-reporting patients (Irigaray et al. 2018).

From the discussion above, it is apparent that static- and ELF-EMF that can affect free radical processes at very low intensities that in turn affect evolution and species survival. In the electromagnetic spectrum, the only other frequency range that biological responses can occur at very low intensity is the light spectrum. It has been shown that the human visual system is sensitive to one photon (Hecht et al. 1942; Pugh 2018), i.e., the reaction of one photon with one rhodopsin molecule in the retina. Apparently, beneficial selection outcomes in evolution have made the living organism extremely sensitive to these fields.

Here, let us digress to an unrelated but equally important topic: i.e., on the biological effects of radiofrequency radiation (RFR), another segment of the EMF-spectrum that is being intensively studied. Since the presence of RFR in the ambient environment is new in the evolutionary time scale, how are living organisms responsive to RFR? No specific cellular detection and response-mechanisms, other than heating, have been discovered. Biological responses to RFR at very low intensities have been reported (e.g., see Table 1 in Levitt and Lai (2010)). But, most of those studies were on modulated fields. Is it possible that the observed biological responses to RFR are actually caused by its ELF-modulations, since almost all environmental RFR sources are modulated (see discussion in section 9 "Effects below 4W/kg: thermal versus nonthermal" in Levitt and Lai (2010))? In the literature, biological effects of ELF-EMF and RFR are found to be very similar (e.g., compare the neurological effects of RFR described in Lai (2018) to those of ELF-EMF (see section on "neurological effects of ELF-EMF" Bioinitiative Report (2012))). In that sense, one can deduce that there is no other significant RFR effect other than thermal effect. Effects of low-level non-modulated continuous-wave (CW) RFR may be a counterargument. However, it is difficult to produce non-modulated RFR in the laboratory, or micro-thermal effect can occur under CW-RFR exposure. There are only several studies showing effects of very low-level CW-RFR (e.g., with specific absorption rate (SAR) ~10 mW/kg). Positive results were reported by de Pomerai et al. (2003) (aggregation of bovine serum albumin and changes in protein conformation, 1 GHz CW, 15–20 mW/kg); Marinelli et al. (2004) (cell self-defense responses, 900 MHz CW, 3.5 mW/kg); D'Inzeo et al. (1988) (acetylcholine-related ion channel, 10.75 GHz CW, 8 mW/kg); Persson et al. (1997) (blood-brain barrier permeability, 915 MHz CW, 0.4 mW/kg); and Tattersall et al. 2001) (hippocampal functions, 700 MHz CW, 1.6 mW/kg). Somosy et al. (1991) (molecular and structural changes in cells of mouse embryos, 2450 MHz) reported that modulated radiation (effect observed at 2.4 mW/kg) is more potent that CW radiation (effect observed at 240 mW/kg). Navakitkia and Tomashevskaya (1994) (behavioral and endocrine changes, 2450 MHz, 2.7 mW/kg with modulation), Schwartz et al. (1990) (calcium movement in heart, 2450 MHz, 0.15 mW/kg with modulation) and Wolke et al. (1996) (calcium concentration in heart muscle cells, 900 MHz, 1 mW/kg with modulation) reported effects with modulated radiation and not with CW radiation. The SARs given were averaged SARs. There is a study that showed DNA damage in human glial cells after exposure to a 50 Hz-modulated 900-MHz RFR but not to CW field. In that study, only an exposure power density of 26 $\mu W/cm^2$ was provided. Other than the Persson et al. (1997) study, all the other studies were carried out in vitro. Interestingly, the Persson et al. (1997) paper reported that CW- is more potent than modulated-915 MHz radiation on increasing blood-brain barrier permeability. Certainly, the RF-carrier could affect the distribution of energy in the exposed subject. And, the pattern of energy distribution can affect biological responses to EMF (Lai et al. 1984). The concept of interaction of modulation with the RF-carrier is not new. It was shown in an earlier study (Bawin et al. 1978) that 6- and 16-Hz amplitude-modulated 147-MHz RFR (0.8 mW/cm^2) increased calcium efflux from chick cerebral tissues, whereas 6- and 16-Hz fields alone caused a decrease in efflux. Lastly, I like to point out that there are not enough research data to support the popular belief that "modulated is more biologically potent that non-modulated RFR." More experiments using the same exposure set-up with continuous-wave and modulated RFR of the same frequency and with intensities that produce the same averaged SAR are needed to reach such a conclusion.

Concluding remarks

(1) Change in cellular free radical activity is one of the most consistent effects of static- and ELF-EMF on living organisms.
(2) The mechanisms by which static- and ELF-EMF affect cellular free radical processes is not well understood. The "radical pair" hypothesis is a likely candidate, particularly the

involvement of cryptochromes. It allows immediate detection and response to changes in static- and ELF-EMF in the environment, which likely play important roles in the evolution of living organisms.

(3) Oxidative responses to static- and ELF-EMF are probably dependent on the characteristic of the field and exposure (such as frequency, modulation, and duration) and the exposed object (such as cell type, and states of biological activities),

(4) However, chronic exposure that leads to the excessive and persistent presence of free radicals can cause oxidative stress and should be avoided.

(5) Effects of static- and ELF-EMF on free radicals probably have beneficial health effects particularly relating to cell proliferation, differentiation, cell death, and cell cycle. These are effects that could influence cancer development and treatment, growth and development, regeneration, and healing.

(6) In future research, it is imperative to identify the field parameters that can selectively cause beneficial or detrimental health effects.

Conflict of interest statement

The author declares no conflict of interest.

References

Abuasbi, F., A. Lahham, and I. R. Abdel-Raziq. 2018a. Residential exposure to extremely low frequency electric and magnetic fields in the city of Ramallah-Palestine. *Radiat. Prot. Dosimetry.* 179:49–57. doi:10.1093/rpd/ncx209.

Abuasbi, F., A. Lahham, and I. R. Abdel-Raziq. 2018b. Levels of extremely low-frequency electric and magnetic fields from overhead power lines in the outdoor environment of Ramallah City- Palestine. *Radiat. Prot. Dosimetry.* 179:229–32. doi:10.1093/rpd/ncx259.

Aher, Y. D., S. Subramaniyan, B. Shanmugasundaram, A. Sase, S. R. Saroja, M. Holy, H. Höger, T. Beryozkina, H. H. Sitte, J. J. Leban, et al. 2016. A novel heterocyclic compound CE-104 enhances spatial working memory in the radial arm maze in rats and modulates the dopaminergic system. *Front. Behav. Neurosci.* 10:55. doi:10.3389/fnbeh.2016.00020.

Ahmad, M., P. Galland, T. Ritz, and R. Wiltschko. 2007. Magnetic intensity affects cryptochrome-dependent responses in Arabidopsis thaliana. *Planta* 225:615–24. doi:10.1007/s00425-006-0416-8.

Akan, Z., B. Aksu, A. Tulunay, S. Bilsel, and A. Inhan-Garip. 2010. Extremely low-frequency electromagnetic fields affect the immune response of monocyte-derived macrophages to pathogens. *Bioelectromagnetics* 31:603–12. doi:10.1002/bem.20607.

Akbarnejad, Z., K. Esmaeilpour, M. Shabani, M. Asadi-Shekaari, M. Saeedi Goraghani, and M. Ahmadi-Zeidabadi. 2018. Spatial memory recovery in Alzheimer's rat model by electromagnetic field exposure. *Int. J. Neurosci.* 128:691–96. doi:10.1080/00207454.2017.1411353.

Akpınar, D., D. K. Gok, E. Hidisoglu, M. Aslan, S. Ozen, A. Agar, and P. Yargicoglu. 2016. Effects of pre- and postnatal exposure to extremely low-frequency electric fields on mismatch negativity component of the auditory event-related potentials: Relation to oxidative stress. *Electromagn. Biol. Med.* 35:245–59. doi:10.3109/15368378.2015.1076727.

Akpinar, D., N. Ozturk, S. Ozen, A. Agar, and P. Yargicoglu. 2012. The effect of different strengths of extremely low-frequency electric fields on antioxidant status, lipid peroxidation, and visual evoked potentials. *Electromagn. Biol. Med.* 31:436–48. doi:10.3109/15368378.2012.692342.

Ansari, A. M., S. Farzampour, A. Sadr, B. Shekarchi, and K. Majidzadeh-A. 2016. Effects of short term and long term extremely low frequency magnetic field on depressive disorder in mice: Involvement of nitric oxide pathway. *Life Sci.* 146:52–57. doi:10.1016/j.lfs.2015.12.055.

Ayşe, I.-G., A. Zafer, O. Sule, I.-T. Işil, and T. Kalkan. 2010. Differentiation of K562 cells under ELF-EMF applied at different time courses. *Electromagn. Biol. Med.* 29:122–30. doi:10.3109/15368378.2010.502451.

Baliatsas, C., I. Van Kamp, E. Lebret, and G. J. Rubin. 2012. Idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF): A systematic review of identifying criteria. *BMC Public Health* 12:643. doi:10.1186/1471-2458-12-643.

Barnes, F. S., and B. Greenebaum. 2015. The effects of weak magnetic fields on radical pairs. *Bioelectromagnetics* 36:45–54. doi:10.1002/bem.21883.

Bawin, S. M., A. Sheppard, and W. R. Adey. 1978. Possible mechanisms of weak electromagnetic field coupling in brain tissue. *Bioelectrochem. Bioenerg.* 5:67–76. doi:10.1016/0302-4598(87)87008-3.

Bawin, S. M., W. M. Satmary, R. A. Jones, W. R. Adey, and G. Zimmerman. 1996. Extremely-low-frequency magnetic fields disrupt rhythmic slow activity in rat hippocampal slices. *Bioelectromagnetics* 17:388–95. doi:10.1002/(SICI)1521-186X(1996)17:5<388::AID-BEM6>3.0.CO;2-#.

Bediz, C. S., A. K. Baltaci, R. Mogulkoc, and E. Oztekin. 2006. Zinc supplementation ameliorates electromagnetic field-induced lipid peroxidation in the rat brain. *Tohoku J. Exp. Med.* 208:133–40. doi:10.1620/tjem.208.133.

Begall, S., J. Cerveny, J. Neef, O. Vojtech, and H. Burda. 2008. Magnetic alignment in grazing and resting cattle and deer. *Proc. Natl. Acad. Sci. U.S.A.* 105:13451–5. doi:10.1073/pnas.0803650105.

Belova, N. A., M. M. Potselueva, L. K. Srebnitskaya, A. V. Znobishcheva, and V. V. Lednev. 2010. The influence of weak magnetic fields on the production of the reactive oxygen species in peritoneal neutrophils of mice. *Biophysics (Biofizika)* 55:586–91. doi:10.1134/S0006350910040123.

Benassi, B., G. Filomeni, C. Montagna, C. Merla, V. Lopresto, R. Pinto, C. Marino, and C. Consales. 2016. Extremely low frequency magnetic field (ELF-MF) exposure sensitizes SH-SY5Y cells to the Pro-Parkinson's disease toxin MPP(.). *Mol. Neurobiol.* 53:4247–60. doi:10.1007/s12035-015-9354-4.

Binhi, V. N., and F. S. Prato. 2017. A physical mechanism of magnetoreception: Extension and analysis. *Bioelectromagnetics* 38:41–52. doi:10.1002/bem.22011.

Bioinitiative Report 2012. Edited by Sage C and Carpenter D. Accessed April, 2019: https://www.bioinitiative.org/.

Bobkova, N. V., V. V. Novikov, N. I. Medvinskaya, I. Y. Aleksandrova, I. V. Nesterova, and E. E. Fesenko. 2018. Effect of weak combined static and extremely low-frequency alternating magnetic fields on spatial memory and brain amyloid-β in two animal models of Alzheimer's disease. *Electromagn. Biol. Med.* 37:127–37. doi:10.1080/15368378.2018.1471700.

Brothers, J. R., and K. J. Lohmann. 2015. Evidence for geomagnetic imprinting and magnetic navigation in the natal homing of sea turtles. *Curr. Biol.* 25:392–96. doi:10.1016/j.cub.2014.12.035.

Budziosz, J., A. Stanek, A. Sieroń, J. Witkoś, A. Cholewka, and K. Sieroń. 2018. Effects of low-frequency electromagnetic field on oxidative stress in selected structures of the central nervous system. *Oxid Med Cell Longev* 2018:1–8. doi:10.1155/2018/1427412.

Burda, H., S. Begall, J. Cervený, J. Neef, and P. Nemec. 2009. Extremely low-frequency electromagnetic fields disrupt magnetic alignment of ruminants. *Proc. Natl. Acad. Sci. U.S.A.* 106:5708–13. doi:10.1073/pnas.0811194106.

Bürgi, A., S. Sagar, B. Struchen, S. Joss, and M. Röösli. 2017. Exposure modelling of extremely low-frequency magnetic fields from overhead power lines and its validation by measurements. *Int. J. Environ. Res. Public. Health.* 14:pii: E949. doi:10.3390/ijerph14090949.

Calcabrini, C., U. Mancini, R. De Bellis, A. R. Diaz, M. Martinelli, L. Cucchiarini, P. Sestili, V. Stocchi, and L. Potenza. 2017. Effect of extremely low-frequency electromagnetic fields on antioxidant activity in the human keratinocyte cell line NCTC 2544. *Biotechnol. Appl. Biochem.* 64:415–22. doi:10.1002/bab.1495.

Calota, V., S. Dragoiu, A. Meghea, and M. Giurginca. 2006. Decrease of luminol chemiluminescence upon exposure of human blood serum to 50 Hz electric fields. *Bioelectrochemistry* 69:126–27. doi:10.1016/j.bioelechem.2005.12.006.

Cichoń, N., M. Bijak, E. Miller, J. Saluk, C. S. Bediz, A. K. Baltaci, R. Mogulkoc, and E. Oztekin. 2017a. Extremely low frequency electromagnetic field (ELF-EMF) reduces oxidative stress and improves functional and psychological status in ischemic stroke patients. *Bioelectromagnetics* 38:386–96. doi:10.1002/bem.v38.5.

Cichoń, N., P. Czarny, M. Bijak, E. Miller, T. Śliwiński, J. Szemraj, and J. Saluk-Bijak. 2017b. Benign effect of extremely low-frequency electromagnetic field on brain plasticity assessed by nitric oxide metabolism during post-stroke rehabilitation. *Oxid Med Cell Longev* 2017:1–9. doi:10.1155/2017/2181942.

Cichoń, N., P. Rzeźnicka, M. Bijak, E. Miller, S. Miller, and J. Saluk. 2018. Extremely low frequency electromagnetic field reduces oxidative stress during the rehabilitation of post-acute stroke patients. *Adv. Clin. Exp. Med.* 27:1285–93. doi:10.17219/acem/73699.

Ciejka, E. B., and A. Goraca. 2009. The influence of low-frequency magnetic field on plasma antioxidant capacity and heart rate. *Wiad. Lek.* 62:81–86.

Consales, C., M. Panatta, A. Butera, G. Filomeni, C. Merla, M. T. Carrì, C. Marino, and B. Benassi. 2019. 50-Hz magnetic field impairs the expression of iron-related genes in the in vitro $SOD1^{G93A}$ model of amyotrophic lateral sclerosis. *Int. J. Radiat. Biol.* 95:368–77. doi:10.1080/09553002.2019.1552378.

Crocetti, S., C. Beyer, G. Schade, M. Egli, J. Fröhlich, A. Franco-Obregón, and I. Ulasov. 2013. Low intensity and frequency pulsed electromagnetic fields selectively impair breast cancer cell viability. *PLoS ONE* 8:e72944. doi:10.1371/journal.pone.0072944.

Cui, Y., Z. Ge, J. D. Rizak, C. Zhai, Z. Zhou, S. Gong, Y. Che, and P. A. Adlard. 2012. Deficits in water maze performance and oxidative stress in the hippocampus and striatum induced by extremely low frequency magnetic field exposure. *PLoS ONE* 7:e32196. doi:10.1371/journal.pone.0032196.

Curley, S. A., F. Palalon, K. E. Sanders, and N. Koshkina. 2014. The effects of non-invasive radiofrequency treatment and hyperthermia on malignant and nonmalignant cells, Int. *Int. J. Environ. Res. Public. Health.* 11:9142–53. doi:10.3390/ijerph110909142.

D'Inzeo, G., P. Bernardi, F. Eusebi, F. Grassi, C. Tamburello, and B. M. Zani. 1988. Microwave effects on acetylcholine-induced channels in cultured chick myotubes. *Bioelectromagnetics* 9:363–72.

De Mattei, M., M. Pasello, A. Pellati, G. Stabellini, L. Massari, D. Gemmati, and A. Caruso. 2003. Effects of electromagnetic fields on proteoglycan metabolism of bovine articular cartilage explants. *Connect. Tissue Res.* 44:154–59.

De Nicola, M., S. Cordisco, C. Cerella, M. C. Albertini, M. D'Alessio, A. Accorsi, A. Bergamaschi, A. Magrini, and L. Ghibelli. 2006. Magnetic fields protect from apoptosis via redox alteration. *Ann. N. Y. Acad. Sci.* 1090:59–68. doi:10.1196/annals.1378.006.

de Pomerai, D. I., B. Smith, A. Dawe, K. North, T. Smith, D. B. Archer, I. R. Duce, D. Jones, and E. P. M. Candido. 2003. Microwave radiation can alter protein conformation without bulk heating. *FEBS Lett.* 543:93–97. doi:10.1016/s0014-5793(03)00413-7.

Deng, Y., Y. Zhang, S. Jia, J. Liu, Y. Liu, W. Xu, and L. Liu. 2013. Effects of aluminum and extremely low frequency electromagnetic radiation on oxidative stress and memory in brain of mice. *Biol. Trace Elem. Res.* 156:243–52. doi:10.1007/s12011-013-9847-9.

Dey, S., S. Bose, S. Kumar, R. Rathore, R. Mathur, and S. Jain. 2017. Extremely low frequency magnetic field protects injured spinal cord from the microglia- and iron-induced tissue damage. *Electromagn. Biol. Med.* 36:330–40. doi:10.1080/15368378.2017.1389750.

Di Loreto, S., S. Falone, V. Caracciolo, P. Sebastiani, A. D'Alessandro, A. Mirabilio, V. Zimmitti, and F. Amicarelli. 2009. Fifty hertz extremely low-frequency magnetic field exposure elicits redox and trophic response in rat-cortical neurons. *J. Cell Physiol.* 219:334–43. doi:10.1002/jcp.21674.

Ding, G.-R., T. Nakahara, H. Hirose, S. Koyama, Y. Takashima, and J. Miyakoshi. 2004. Extremely low frequency magnetic fields and the promotion of H_2O_2--induced cell death in HL-60 cells. *Int. J. Radiat. Biol.* 80:317–24. doi:10.1080/09553000410001679802.

Djordjevic, N. Z., M. G. Paunović, and A. S. Peulić. 2017. Anxiety-like behavioural effects of extremely low-frequency

electromagnetic field in rats. *Environ. Sci. Pollut. Res. Int.* 24:21693–99. doi:10.1007/s11356-017-9710-1.

Dodson, C. A., P. J. Hore, and M. I. Wallace. 2013. A radical sense of direction: Signalling and mechanism in cryptochrome magnetoreception. *Trends Biochem. Sci.* 38:435–46. doi:10.1016/j.tibs.2013.07.002.

Duan, Y., Z. Wang, H. Zhang, Y. He, R. Lu, R. Zhang, G. Sun, and X. Sun. 2013. The preventive effect of lotus seedpod procyanidins on cognitive impairment and oxidative damage induced by extremely low frequency electromagnetic field exposure. *Food Funct* 4:1252–62. doi:10.1039/c3fo60116a.

Duong, C. N., and J. Y. Kim. 2016. Exposure to electromagnetic field attenuates oxygen-glucose deprivation-induced microglial cell death by reducing intracellular Ca^{2+} and ROS. *Int. J. Radiat. Biol.* 92:195–201. doi:10.3109/09553002.2016.1136851.

Ehnert, S., A.-K. Fentz, A. Schreiner, J. Birk, B. Wilbrand, P. Ziegler, M. K. Reumann, H. Wang, K. Falldorf, and A. K. Nussler. 2017. Extremely low frequency pulsed electromagnetic fields cause antioxidative defense mechanisms in human osteoblasts via induction of $\bullet O_2^-$ and H_2O_2. *Sci. Rep.* 7:14544. doi:10.1038/s41598-017-14983-9.

Emre, M., S. Cetiner, S. Zencir, I. Unlukurt, I. Kahraman, and Z. Topcu. 2011. Oxidative stress and apoptosis in relation to exposure to magnetic field. *Cell. Biochem. Biophys.* 59:71–77. doi:10.1007/s12013-010-9113-0.

Engels, S., N.-L. Schneider, N. Lefeldt, C. M. Hein, M. Zapka, A. Michalik, D. Elbers, A. Kittel, P. J. Hore, and H. Mouritsen. 2014. Anthropogenic electromagnetic noise disrupts magnetic compass orientation in a migratory bird. *Nature* 509:353–56. doi:10.1038/nature13290.

Errico Provenzano, A., S. Amatori, M. G. Nasoni, G. Persico, S. Russo, A. R. Mastrogiacomo, A. Gambarara, and M. Fanelli. 2018. Effects of fifty-hertz electromagnetic fields on granulocytic differentiation of ATRA-treated acute promyelocytic leukemia NB4 cells. *Cell. Physiol. Biochem.* 46:389–400. doi:10.1159/000488473.

Falone, S., M. R. Grossi, B. Cinque, B. D'Angelo, E. Tettamanti, A. Cimini, C. Di Ilio, and F. Amicarelli. 2007. Fifty hertz extremely low-frequency electromagnetic field causes changes in redox and differentiative status in neuroblastoma cells. *Int. J. Biochem. Cell. Biol.* 39:2093–106. doi:10.1016/j.biocel.2007.06.001.

Falone, S., N. Marchesi, C. Osera, L. Fassina, S. Comincini, M. Amadio, and A. Pascale. 2016. Pulsed electromagnetic field (PEMF) prevents pro-oxidant effects of H_2O_2 in SK-N-BE(2) human neuroblastoma cells. *Int. J. Radiat. Biol.* 92:281–86. doi:10.3109/09553002.2016.1150619.

Falone, S., S. Santini Jr., V. Cordone, P. Cesare, A. Bonfigli, M. Grannonico, G. Di Emidio, C. Tatone, M. Cacchio, and F. Amicarelli. 2017. Power frequency magnetic field promotes a more malignant phenotype in neuroblastoma cells via redox-related mechanisms. *Sci. Rep.* 7:11470. doi:10.1038/s41598-017-11869-8.

Feagin, J. E., M. A. Wurscher, and C. Ramon. 1999. Magnetic fields and malaria. In M. F. Holick and E. G. Jung, eds. "Biologic Effects of Light: Proceedings of the Biologic Effects of Light Symposium" (pp.343–49), Kluwer Academic Publishers, Hingham, MA, USA.

Feng, B., C. Ye, L. Qiu, L. Chen, Y. Fu, and W. Sun. 2016. Mitochondrial ROS release and subsequent Akt Activation potentially mediated the anti-apoptotic effect of a 50-Hz magnetic field on FL cells. *Cell. Physiol. Biochem.* 38:2489–99. doi:10.1159/000445599.

Fernie, K. J., and D. M. Bird. 2001. Evidence of oxidative stress in American kestrels exposed to electromagnetic fields. *Environ. Res.* 86:198–207. doi:10.1006/enrs.2001.4263.

Fitak, R. R., B. R. Wheeler, D. A. Ernst, K. J. Lohmann, and S. Johnsen. 2017. Candidate genes mediating magnetoreception in rainbow trout (*Oncorhynchus mykiss*). *Biol. Lett* 13:pii: 20170142. doi:10.1098/rsbl.2017.0142.

Fitzsimmons, R. J., S. L. Gordon, J. Kronberg, T. Ganey, and A. A. Pilla. 2008. A pulsing electric field (PEF) increases human chondrocyte proliferation through a transduction pathway involving nitric oxide signaling. *J. Orthop. Res.* 26:854–59. doi:10.1002/jor.20590.

Frahm, J., M. Lantow, M. Lupke, D. G. Weiss, and M. Simkó. 2006. Alteration in cellular functions in mouse macrophages after exposure to 50 Hz magnetic fields. *J. Cell. Biochem.* 99:168–77. doi:10.1002/jcb.20920.

Galler, S., B. G. Wang, and M. Kawai. 2005. Elementary steps of the cross-bridge cycle in fast-twitch fiber types from rabbit skeletal muscles. *Biophys. J.* 89:3248–60. doi:10.1529/biophysj.104.056614.

Garip, A. I., and Z. Akan. 2010. Effect of ELF-EMF on number of apoptotic cells; correlation with reactive oxygen species and HSP. *Acta Biol. Hung.* 61:158–67. doi:10.1556/ABiol.61.2010.2.4.

Ghodbane, S., M. Ammari, A. Lahbib, M. Sakly, and H. Abdelmelek. 2015. Static magnetic field exposure-induced oxidative response and caspase-independent apoptosis in rat liver: Effect of selenium and vitamin E supplementations. *Environ. Sci. Pollut. Res. Int.* 22:16060–66. doi:10.1007/s11356-015-4802-2.

Giorgi, G., C. Pirazzini, M. G. Bacalini, C. Giuliani, P. Garagnani, M. Capri, F. Bersani, and B. Del Re. 2017. Assessing the combined effect of extremely low-frequency magnetic field exposure and oxidative stress on LINE-1 promoter methylation in human neural cells. *Radiat. Environ. Biophys.* 56:193–200. doi:10.1007/s00411-017-0683-8.

Glinka, M., A. Sieroń, E. Birkner, and G. Cieślar. 2013. Influence of extremely low-frequency magnetic field on the activity of antioxidant enzymes during skin wound healing in rats. *Electromagn. Biol. Med.* 32:463–70. doi:10.3109/15368378.2012.743906.

Gourzoulidis, G. A., P. Tsaprouni, N. Skamnakis, C. Tzoumanika, E. Kalampaliki, E. Karastergios, A. Gialofas, A. Achtipis, C. Kappas, and E. Karabetsos. 2018. Occupational exposure to electromagnetic fields. The situation in Greece. *Phys. Med* 49:83–89. doi:10.1016/j.ejmp.2018.05.011.

Guler, G., Z. Turkozer, A. Tomruk, and N. Seyhan. 2008. The protective effects of N-acetyl-L-cysteine and epigallocatechin-3-gallate on electric field-induced hepatic oxidative stress. *Int. J. Radiat. Biol.* 84:669–80. doi:10.1080/09553000802241747.

Güler, G., Z. Türközer, E. Ozgur, A. Tomruk, N. Seyhan, and Ç. Karasu. 2009a. Protein oxidation under extremely low frequency electric field in guinea pigs. Effect of N-acetyl-L-cysteine treatment. *Gen. Physiol. Biophys.* 28:47–55. doi:10.4149/gpb_2009_01_47.

Güler, G., Z. Türközer, E. Ozgur, and N. Seyhan. 2009b. Antioxidants alleviate electric field-induced effects on

lung tissue based on assays of heme oxygenase-1, protein carbonyl content, malondialdehyde, nitric oxide, and hydroxyproline. *Sci. Total Environ.* 407:1326–32. doi:10.1016/j.scitotenv.2008.10.050.

Gunnarsson, L. G., and L. Bodin. Oct 26 2018. Amyotrophic lateral sclerosis and occupational exposures: A systematic literature review and meta-analyses. *Int. J. Environ. Res. Public Health.* 15:pii: E2371. doi:10.3390/ijerph15061188.

Haghighat, N., P. Abdolmaleki, J. Parnian, and M. Behmanesh. 2017a. The expression of pluripotency and neuronal differentiation markers under the influence of electromagnetic field and nitric oxide. *Mol. Cell. Neurosci.* 85:19–28. doi:10.1016/j.mcn.2017.08.005.

Haghighat, N., P. Abdolmaleki, M. Behmanesh, and M. Satari. 2017b. Stable morphological-physiological and neural protein expression changes in rat bone marrow mesenchymal stem cells treated with electromagnetic field and nitric oxide. *Bioelectromagnetics* 38:592–601. doi:10.1002/bem.v38.8.

Hajipour Verdom, B., P. Abdolmaleki, and M. Behmanesh. 2018. The static magnetic field remotely boosts the efficiency of doxorubicin through modulating ROS behaviors. *Sci. Rep.* 8:990. doi:10.1038/s41598-018-19247-8.

Hajnorouzi, A., M. Vaezzadeh, F. Ghanati, H. Jamnezhad, and B. Nahidian. 2011. Growth promotion and a decrease of oxidative stress in maize seedlings by a combination of geomagnetic and weak electromagnetic fields. *J. Plant Physiol.* 168:1123–28. doi:10.1016/j.jplph.2010.12.003.

Harakawa, S., N. Inoue, T. Hori, K. Tochio, T. Kariya, K. Takahashi, F. Doge, H. Suzuki, and H. Nagasawa. 2005. Effects of a 50 Hz electric field on plasma lipid peroxide level and antioxidant activity in rats. *Bioelectromagnetics* 26:589–94. doi:10.1002/bem.20137.

Hart, V., E. P. Malkemper, T. Kušta, S. Begall, P. Nováková, V. Hanzal, L. Pleskač, M. Ježek, R. Policht, V. Husinec, et al. 2013b. Directional compass preference for landing in water birds. *Front. Zool.* 10:38. doi:10.1186/1742-9994-10-38.

Hart, V., P. Nováková, E. P. Malkemper, S. Begall, V. Hanzal, M. Ježek, T. Kušta, V. Němcová, J. Adámková, K. Benediktová, et al. 2013a. Dogs are sensitive to small variations of the Earth's magnetic field. *Front. Zool.* 10:80. doi:10.1186/1742-9994-10-80.

Hart, V., T. Kušta, P. Němec, V. Bláhová, M. Ježek, P. Nováková, S. Begall, J. Červený, V. Hanzal, E. P. Malkemper, et al. 2012. Magnetic alignment in carps: Evidence from the Czech Christmas fish market. *PLoS ONE* 7:e51100. doi:10.1371/journal.pone.0051100.

Hecht, S., S. Shlaer, and M. H. Pirenne. 1942. Energy, quanta, and vision. *J. Gen. Physiol* 25:819–40. doi:10.1085/jgp.25.6.819.

Hore, P. J. Feb 2019. Upper bound on the biological effects of 50/60 Hz magnetic fields mediated by radical pairs. *Elife* 25:pii: e44179. doi: 10.7554/eLife.44179.

Hore, P. J., and H. Mouritsen. 2016. The radical-pair mechanism of magnetoreception. *Annu. Rev. Biophys.* 45:299–344. doi:10.1146/annurev-biophys-032116-094545.

Hu, Y., J. Lai, B. Wan, X. Liu, Y. Zhang, J. Zhang, D. Sun, G. Ruan, E. Liu, G.-P. Liu, et al. 2016. Long-term exposure to ELF-MF ameliorates cognitive deficits and attenuates tau hyperphosphorylation in 3xTg AD mice. *NeuroToxicology* 53:290–300. doi:10.1016/j.neuro.2016.02.012.

Huss, A., S. Peters, and R. Vermeulen. 2018. Occupational exposure to extremely low-frequency magnetic fields and the risk of ALS: A systematic review and meta-analysis. *Bioelectromagnetics* 39:156–63. doi:10.1002/bem.22104.

Ilonen, K., A. Markkanen, G. Mezei, and J. Juutilainen. 2008. Indoor transformer stations as predictors of residential ELF magnetic field exposure. *Bioelectromagnetics* 29:213–18. doi:10.1002/bem.20385.

Irigaray, P., D. Caccamo, and D. Belpomme. 2018. Oxidative stress in electrohypersensitivity self-reporting patients: Results of a prospective in vivo investigation with comprehensive molecular analysis. *Int. J. Mol. Med.* 42:1885–98. doi:10.3892/ijmm.2018.3774.

Jajte, J., M. Zmyślony, J. Palus, E. Dziubałtowska, and E. Rajkowska. 2001. Protective effect of melatonin against in vitro iron ions and 7 mT 50 Hz magnetic field-induced DNA damage in rat lymphocytes. *Mutat. Res.* 483:57–64. doi:10.1016/s0027-5107(01)00230-5.

Jalilian, H., S. H. Teshnizi, M. Röösli, and M. Neghab. 2018. Occupational exposure to extremely low frequency magnetic fields and risk of Alzheimer disease: A systematic review and meta-analysis. *NeuroToxicology* 69:242–52. doi:10.1016/j.neuro.2017.12.005.

Jeong, J. H., C. Kum, H. J. Choi, E. S. Park, and U. D. Sohn. 2006. Extremely low frequency magnetic field induces hyperalgesia in mice modulated by nitric oxide synthesis. *Life Sci.* 78:1407–12. doi:10.1016/j.lfs.2005.07.006.

Kamalipooya, S., P. Abdolmaleki, Z. Salemi, F. Javani Jouni, J. Zafari, and H. Soleimani. 2017. Simultaneous application of cisplatin and static magnetic field enhances oxidative stress in HeLa cell line. *In Vitro Cell. Dev. Biol. Anim.* 53:783–90. doi:10.1007/s11626-017-0148-z.

Kantar Gok, D., D. Akpinar, P. Yargicoglu, S. Ozen, M. Aslan, N. Demir, N. Derin, and A. Agar. 2014. Effects of extremely low-frequency electric fields at different intensities and exposure durations on mismatch negativity. *Neuroscience* 272:154–66. doi:10.1016/j.neuroscience.2014.04.056.

Kapri-Pardes, E., T. Hanoch, G. Maik-Rachline, M. Murbach, P. L. Bounds, N. Kuster, and R. Seger. 2017. Activation of signaling cascades by weak extremely low frequency electromagnetic fields. *Cell. Physiol. Biochem.* 43:1533–46. doi:10.1159/000481977.

Karimi, S. A., I. Salehi, T. Shykhi, S. Zare, and A. Komaki. 2019. Effects of exposure to extremely low-frequency electromagnetic fields on spatial and passive avoidance learning and memory, anxiety-like behavior and oxidative stress in male rats. *Behav. Brain Res.* 359:630–38. doi:10.1016/j.bbr.2018.10.002.

Karin, M., and B. Mintz. 1981. Receptor-mediated endocytosis of transferrin in developmentally totipotent mouse teratocarcinoma stem cells. *J. Biol. Chem.* 256:3245–52.

Kavaliers, M., E. Choleris, F. S. Prato, and K. Ossenkopp. 1998. Evidence for the involvement of nitric oxide and nitric oxide synthase in the modulation of opioid-induced antinociception and the inhibitory effects of exposure to 60-Hz magnetic fields in the land snail. *Brain Res.* 809:50–57. doi:10.1016/s0006-8993(98)00844-0.

Kesari, K. K., J. Juutilainen, J. Luukkonen, and J. Naarala. Jan 2016. Induction of micronuclei and superoxide production in neuroblastoma and glioma cell lines exposed to weak 50

Hz magnetic fields. *J R Soc Interface* 13:pii: 20150995. doi:10.1098/rsif.2015.0995.

Kim, S. J., Y. W. Jang, K. E. Hyung, D. K. Lee, K. H. Hyun, S. H. Jeong, K. H. Min, W. Kang, J. H. Jeong, S.-Y. Park, et al. 2017. Extremely low-frequency electromagnetic field exposure enhances inflammatory response and inhibits effect of antioxidant in RAW 264.7 cells. *Bioelectromagnetics* 38:374–85. doi:10.1002/bem.22049.

Kirschvink, J. L., M. M. Walker, and C. E. Diebel. 2001. Magnetite-based magnetoreception. *Curr. Opin. Neurobiol.* 11:462–67. doi:10.1016/S0959-4388(00)00235-X.

Koeman, T., P. Slottje, L. J. Schouten, S. Peters, A. Huss, J. H. Veldink, H. Kromhout, P. A. van Den Brandt, and R. Vermeulen. 2017. Occupational exposure and amyotrophic lateral sclerosis in a prospective cohort. *Occup. Environ. Med.* 74:578–85. doi:10.1136/oemed-2016-103780.

Koh, E. K., B.-K. Ryu, D.-Y. Jeong, I.-S. Bang, M. H. Nam, and K.-S. Chae. 2008. A 60-Hz sinusoidal magnetic field induces apoptosis of prostate cancer cells through reactive oxygen species. *Int. J. Radiat. Biol.* 84:945–55. doi:10.1080/09553000802460206.

Koyama, S., T. Sakurai, T. Nakahara, and J. Miyakoshi. 2008. Extremely low frequency (ELF) magnetic fields enhance chemically induced formation of apurinic/apyrimidinic (AP)sites in A172 cells. *Int. J. Radiat. Biol.* 84:53–59. doi:10.1080/09553000701616064.

Koziorowska, A., M. Romerowicz-Misielak, P. Sołek, and M. Koziorowski. 2018. Extremely low frequency variable electromagnetic fields affect cancer and noncancerous cells in vitro differently: Preliminary study. *Electromagn. Biol. Med.* 37:35–42. doi:10.1080/15368378.2017.1408021.

Lai, H. 2018. A summary of recent literature (2007-2017) on neurobiological effects of radiofrequency radiation. In *Mobile Communications and Public Health*, ed. M. Markov, 187–222. Boca Raton, FL, USA: CRC Press.

Lai, H., A. Horita, C. K. Chou, and A. W. Guy. 1984. Effects of acute low-level microwaves on pentobarbital-induced hypothermia depend on exposure orientation. *Bioelectromagnetics* 5:203–11.

Lai, H., H. W. Chan, and N. P. Singh. 2016. Effects of radiation from a radiofrequency identification (RFID) microchip on human cancer cells. *Int. J. Rad. Biol.* 92:156–61. doi:10.3109/09553002.2016.1135264.

Lai, H., and N. P. Singh. 1997a. Acute exposure to a 60-Hz magnetic field increases DNA strand breaks in rat brain cells. *Bioelectromagnetics* 18:156–65. doi:10.1002/(ISSN)1521-186X.

Lai, H., and N. P. Singh. 1997b. Melatonin and N-tert-butyl -?-phenylnitrone block 60-Hz magnetic field-induced DNA single and double strand breaks in rat brain cells. *J. Pineal Res* 22:152–62. doi:10.1111/jpi.1997.22.issue-3.

Lai, H., and N. P. Singh. 2004. Magnetic field-induced DNA strand breaks in brain cells of the rat. *Environ. Health Perspect.* 112:687–94. doi:10.1289/ehp.6355.

Lai, H., and N. P. Singh 2010. Medical applications of electromagnetic fields. Institute of Physics Conference Series: Earth and Environmental Science, London, UK, 10 012006 (doi: 10.1088/1755-1315/10/1/012006)

Lai, H., N. P. Singh, and T. Sasaki. 2013. Development of artemisinin compounds for cancer treatment. *Invest New Drugs* 31:230–46. doi:10.1007/s10637-012-9873-z.

Landler, L., and D. A. Keays. 2018. Cryptochrome: The magnetosensor with a sinister side? *PLoS Biol.* 16:e3000018. doi:10.1371/journal.pbio.3000018.

Laramee, C. B., P. Frisch, K. McLeod, and G. C. Li. 2014. Elevation of heat shock gene expression from static magnetic field exposure in vitro. *Bioelectromagnetics* 35:406–13. doi:10.1002/bem.21857.

Lee, H.-M., U.-H. Kwon, H. Kim, H.-J. Kim, B. Kim, J.-O. Park, E.-S. Moon, and S.-H. Moon. 2010. Pulsed electromagnetic field stimulates cellular proliferation in human intervertebral disc cells. *Yonsei Med. J.* 51:954–59. doi:10.3349/ymj.2010.51.6.954.

Lee, H.-N., K.-N. Ko, H.-J. Kim, A. Rosebud Aikins, and C.-W. Kim. 2015. Ferritin is associated with neural differentiation of bone marrow-derived mesenchymal stem cells under extremely low-frequency electromagnetic field. *Cell. Mol. Biol. (noisy-le-grand)* 61:55–59.

Levitt, B. B., and H. Lai. 2010. Biological effects from exposure to electromagnetic radiation emitted by cell tower base stations and other antenna arrays. *Environ. Rev.* 18:369–95. doi:10.1139/A10-018.

Li, Y., Y. Zhang, and W. Wang. 2019. Effects of pulsed electromagnetic fields on learning and memory abilities of STZ-induced dementia rats, Electromagn. *Biol. Med.* doi:10.1080/15368378.2019.1591437.

Lian, H.-Y., K.-W. Lin, C. Yang, and P. Cai. 2018. Generation and propagation of yeast prion [URE3] are elevated under electromagnetic field. *Cell Stress Chaperones* 23:581–94. doi:10.1007/s12192-017-0867-9.

Lindgren, M., M. Gustavsson, Y. Hamnerius, and S. Galt. 2001. ELF magnetic fields in a city environment. *Bioelectromagnetics* 22:87–90.

Liu, X., H. Zuo, D. Wang, R. Peng, T. Song, S. Wang, X. Xu, Y. Gao, Y. Li, S. Wang, et al. 2015. Improvement of spatial memory disorder and hippocampal damage by exposure to electromagnetic fields in an Alzheimer's disease rat model. *PLoS ONE* 10:e0126963. doi:10.1371/journal.pone.0126963.

Luo, K., C. Luo, G. Li, X. Yao, R. Gao, Z. Hu, G. Zhang, and H. Zhao. 2019. High-voltage electrostatic field-induced oxidative stress: Characterization of the physiological effects in Sitobion avenae (Hemiptera: Aphididae) across multiple generations. *Bioelectromagnetics* 40:52–61. doi:10.1002/bem.22157.

Maes, A., R. Anthonissen, and L. Verschaeve. 2016. On the allerged association between extremely low frequency magnetic field exposures and increase risk of Alzheimer's disease. *Rad. Applic.* 1:151–54.

Makinistian, L., E. Marková, and I. Belyaev. 2019. A high throughput screening system of coils for ELF magnetic fields experiments: Proof of concept on the proliferation of cancer cell lines. *BMC Cancer* 19:188. doi:10.1186/s12885-019-5699-9.

Malewski, S., E. P. Malkemper, F. Sedláček, R. Šumbera, K. R. Caspar, H. Burda, and S. Begall. 2018. Attracted by a magnet: Exploration behaviour of rodents in the presence of magnetic objects. *Behav. Processes.* 151:11–15. doi:10.1016/j.beproc.2018.02.023.

Malkemper, E. P., S. H. K. Eder, S. Begall, J. B. Phillips, M. Winklhofer, V. Hart, and H. Burda. 2015. Magnetoreception in the wood mouse (Apodemus

sylvaticus): Influence of weak frequency-modulated radio frequency fields. *Sci. Rep.* 5:9917. doi:10.1038/srep09917.

Manger, P. R., and J. D. Pettigrew. 1996. Ultrastructure, number, distribution and innervation of electroreceptors and mechanoreceptors in the bill skin of the platypus, Ornithorhynchus anatinus. *Brain Behav. Evol.* 48:27–54. doi:10.1159/000113185.

Manikonda, P. K., P. Rajendra, D. Devendranath, B. Gunasekaran, R. S. Aradhya, R. B. Sashidhar, and C. Subramanyam. 2014. Extremely low frequency magnetic fields induce oxidative stress in rat brain. *Gen. Physiol. Biophys.* 33:81–90. doi:10.4149/gpb_2013059.

Mannerling, A.-C., M. Simkó, K. H. Mild, and M.-O. Mattsson. 2010. Effects of 50-Hz magnetic field exposure on superoxide radical anion formation and HSP70 induction in human K562 cells. *Radiat. Environ. Biophys.* 49:731–41. doi:10.1007/s00411-010-0306-0.

Marinelli, F., D. La Sala, G. Cicciotti, L. Cattini, C. Trimarchi, S. Putti, A. Zamparelli, L. Giuliani, G. Tomassetti, and C. Cinti. 2004. Exposure to 900 MHz electromagnetic field induces an unbalance between pro-apoptotic and pro-survival signals in T-lymphoblastoid leukemia CCRF-CEM cells. *J. Cell. Physiol.* 198:324–32. doi:10.1002/jcp.10425.

Martínez, M. A., A. Úbeda, J. Moreno, and M. Trillo. 2016. Power frequency magnetic fields affect the p38 MAPK-mediated regulation of NB69 cell proliferation implication of free radicals. *Int. J. Mol. Sci.* 17:510. doi:10.3390/ijms17040510.

Martino, C. F., and P. R. Castello. 2011. Modulation of hydrogen peroxide production in cellular systems by low level magnetic fields. *PLoS ONE* 6:e22753. doi:10.1371/journal.pone.0022753.

Marycz, K., K. Kornicka, and M. Röcken. 2018. Static magnetic field (SMF) as a regulator of stem cell fate - new perspectives in regenerative medicine arising from an underestimated tool. *Stem Cell Rev* 14:785–92. doi:10.1007/s12015-018-9847-4.

May, W. S., and W. S. Cuatrecasas. 1985. Transferrin receptor: Its biological significance. *J. Membrane Biol.* 88:205–15. doi:10.1007/BF01871086.

Miliša, M., D. Đikić, T. Mandić, D. Grozić, I. Čolić, and A. Ostojić. 2017. Response of aquatic protists to electric field exposure. *Int. J. Radiat. Biol.* 93:818–30. doi:10.1080/09553002.2017.1321809.

Mohammadi, F., F. Ghanati, M. Sharifi, and N. A. Chashmi. 2018. On the mechanism of the cell cycle control of suspension-cultured tobacco cells after exposure to static magnetic field. *Plant Sci.* 277:139–44. doi:10.1016/j.plantsci.2018.08.004.

Montgomery, J. C., and D. Bodznick. 1999. Signals and noise in the elasmobranch electrosensory system. *J. Exp. Biol.* 202:1349–55.

Morabito, C., S. Guarnieri, G. Fanò, and M. A. Mariggiò. 2010. Effects of acute and chronic low frequency electromagnetic field exposure on PC12 cells during neuronal differentiation. *Cell. Physiol. Biochem.* 26:947–58. doi:10.1159/000324003.

Morotomi-Yano, K., H. Akiyama, and K. Yano. 2014. Different involvement of extracellular calcium in two modes of cell death induced by nanosecond pulsed electric fields. *Arch. Biochem. Biophys* 555–556:47–54. doi:10.1016/j.abb.2014.05.020.

Naarala, J., K. K. Kesari, I. McClure, C. Chavarriaga, J. Juutilainen, and C. F. Martino. 2017. Direction-dependent effects of combined static and ELF magnetic fields on cell proliferation and superoxide radical production. *Biomed Res Int* 2017:1–8. doi:10.1155/2017/5675086.

Naisbett-Jones, L. C., N. F. Putman, J. F. Stephenson, S. Ladak, and K. A. Young. 2017. A magnetic map leads juvenile European eels to the gulf stream. *Curr. Biol.* 27:1236–40. doi:10.1016/j.cub.2017.03.015.

Navakatikian, M. A., and L. A. Tomashevskaya. 1994. Phasic behavioral and endocrine effects of microwaves of non-thermal intensity. In *Biological effects of electric and magnetic fields*, ed. D. O. Carpenter, Vol. 1., pp. 333–342. San Diego, CA, USA: Academic Press.

Osera, C., L. Fassina, M. Amadio, L. Venturini, E. Buoso, G. Magenes, S. Govoni, G. Ricevuti, and A. Pascale. 2011. Cytoprotective response induced by electromagnetic stimulation on SH-SY5Y human neuroblastoma cell line. *Tissue Eng. Part A.* 17:2573–82. doi:10.1089/ten.TEA.2011.0071.

Osera, C., M. Amadio, S. Falone, L. Fassina, G. Magenes, F. Amicarelli, G. Ricevuti, S. Govoni, and A. Pascale. 2015. Pre-exposure of neuroblastoma cell line to pulsed electromagnetic field prevents H_2O_2 -induced ROS production by increasing MnSOD activity. *Bioelectromagnetics* 36:219–32. doi:10.1002/bem.21900.

Pakhomova, O. N., V. A. Khorokhorina, A. M. Bowman, R. Rodaitė-Riševičienė, G. Saulis, S. Xiao, and A. G. Pakhomov. 2012. Oxidative effects of nanosecond pulsed electric field exposure in cells and cell-free media. *Arch. Biochem. Biophys.* 527:55–64. doi:10.1016/j.abb.2012.08.004.

Park, J.-E., Y.-K. Seo, -H.-H. Yoon, C.-W. Kim, J.-K. Park, and S. Jeon. 2013. Electromagnetic fields induce neural differentiation of human bone marrow derived mesenchymal stem cells via ROS mediated EGFR activation. *Neurochem. Int.* 62:418–24. doi:10.1016/j.neuint.2013.02.002.

Patruno, A., P. Amerio, M. Pesce, G. Vianale, S. Di Luzio, A. Tulli, S. Franceschelli, A. Grilli, R. Muraro, and M. Reale. 2010. Extremely low frequency electromagnetic fields modulate expression of inducible nitric oxide synthase, endothelial nitric oxide synthase and cyclooxygenase-2 in the human keratinocyte cell line HaCat: Potential therapeutic effects in wound healing. *Br. J. Dermatol.* 162:258–66. doi:10.1111/j.1365-2133.2009.09527.x.

Patruno, A., S. Tabrez, P. Amerio, M. Pesce, G. Vianale, S. Franceschelli, A. Grilli, M. A. Kamal, and M. Reale. 2011. Kinetic study on the effects of extremely low frequency electromagnetic field on catalase, cytochrome P450 and inducible nitric oxide synthase in human HaCaT and THP-1 cell lines. *CNS Neurol. Disord. Drug Targets.* 10:936–44.

Pedersen, C., A. H. Poulsen, N. H. Rod, P. Frei, J. Hansen, K. Grell, O. Raaschou-Nielsen, J. Schüz, and C. Johansen. 2017. Occupational exposure to extremely low-frequency magnetic fields and risk for central nervous system disease: An update of a Danish cohort study among utility workers. *Int. Arch. Occup. Environ. Health.* 90:619–28. doi:10.1007/s00420-017-1224-0.

Persson, B. R. R., L. G. Salford, and A. Brun. 1997. Blood-brain barrier permeability in rats exposed to electromagnetic fields used in wireless communication. *Wireless Network* 3:455–61. doi:10.1023/A:1019150510840.

Pishchalnikov, R. Y., Y. I. Gurfinkel, R. M. Sarimov, A. L. Vasin, M. L. Sasonko, T. A. Matveeva, V. N. Binhi, and M. V. Baranov. 2019. Cardiovascular response as a marker of environmental stress caused by variations in geomagnetic field and local weather. *Biomed Signal Process Control* 51:401–10. doi:10.1016/j.bspc.2019.03.005.

Pizzino, G., N. Irrera, M. Cucinotta, G. Pallio, F. Mannino, V. Arcoraci, F. Squadrito, D. Altavilla, and A. Bitto. 2017. Oxidative stress: Harms and benefits for human health. *Oxid. Med. Cell. Longevity* 2017:1–13. doi:10.1155/2017/8416763.

Poniedzialek, B., P. Rzymski, H. Nawrocka-Bogusz, F. Jaroszyk, and K. Wiktorowicz. 2013. The effect of electromagnetic field on reactive oxygen species production in human neutrophils in vitro. *Electromagn. Biol. Med.* 32:333–41. doi:10.3109/15368378.2012.721845.

Poprac, P., K. Jomova, M. Simunkova, V. Kollar, C. J. Rhodes, and M. Valko. 2017. Targeting free radicals in oxidative stress-related human diseases. *Trends Pharmacol. Sci.* 38:592–607. doi:10.1016/j.tips.2017.04.005.

Pugh, E. N. 2018. The discovery of the ability of rod photoreceptors to signal single photons. *J. Gen. Physiol.* 150:383–88. doi:10.1085/jgp.201711970.

Putman, N. F., A. M. Meinke, and D. L. G. Noakes. 2014b. Rearing in a distorted magnetic field disrupts the 'map sense' of juvenile steelhead trout. *Biol. Lett* 10:pii: 20140169. doi:10.1098/rsbl.2014.0169.

Putman, N. F., E. S. Jenkins, C. G. J. Michielsens, and D. L. G. Noakes. 2014a. Geomagnetic imprinting predicts spatio-temporal variation in homing migration of pink and sockeye salmon. *J. R. Soc. Interface.* 11:20140542. doi:10.1098/rsif.2014.0542.

Qiu, L., L. Chen, X. Yang, A. Ye, W. Jiang, and W. Sun. 2019. S1P mediates human amniotic cells proliferation induced by a 50-Hz magnetic field exposure via ERK1/2 signaling pathway. *J. Cell. Physiol.* 234:7734–41. doi:10.1002/jcp.28102.

Rauš Balind, S., V. Selaković, L. Radenović, Z. Prolić, B. Janać, and T. V. Arumugam. 2014. Extremely low frequency magnetic field (50 Hz, 0.5 mT) reduces oxidative stress in the brain of gerbils submitted to global cerebral ischemia. *PLoS ONE* 9:e88921. doi:10.1371/journal.pone.0088921.

Regoli, F., S. Gorbi, N. Machella, S. Tedesco, M. Benedetti, R. Bocchetti, A. Notti, D. Fattorini, F. Piva, and G. Principato. 2005. Pro-oxidant effects of extremely low frequency electromagnetic fields in the land snail Helix aspersa. *Free Radic. Biol. Med.* 39:1620–28. doi:10.1016/j.freeradbiomed.2005.08.004.

Reizenstein, P. 1991. Iron, free radicals and cancer. *Med. Oncol. Tumor Pharmacother.* 8:229–33.

Romeo, S., A. Sannino, M. R. Scarfì, R. Massa, R. d'Angelo, and O. Zeni. 2016. Lack of effects on key cellular parameters of MRC-5 human lung fibroblasts exposed to 370 mT static magnetic field. *Sci. Rep* 6:19398. doi:10.1038/srep19398.

Sadeghipour, R., S. Ahmadian, B. Bolouri, Y. Pazhang, and M. Shafiezadeh. 2012. Effects of extremely low-frequency pulsed electromagnetic fields on morphological and biochemical properties of human breast carcinoma cells (T47D). *Electromagn. Biol. Med.* 31:425–35. doi:10.3109/15368378.2012.683844.

Sakhaie, M. H., M. Soleimani, B. Pourheydar, Z. Majd, P. Atefimanesh, S. S. Asl, and M. Mehdizadeh. 2017. Effects of extremely low-frequency electromagnetic fields on neurogenesis and cognitive behavior in an experimental model of hippocampal injury. *Behav. Neurol.* 2017:1–9. doi:10.1155/2017/9194261.

Salunke, B. P., S. N. Umathe, and J. G. Chavan. 2014. Experimental evidence for involvement of nitric oxide in low frequency magnetic field induced obsessive compulsive disorder-like behavior. *Pharmacol. Biochem. Behav.* 122:273–78. doi:10.1016/j.pbb.2014.04.007.

Schwartz, J. L., D. E. House, and G. A. Mealing. 1990. Exposure of frog hearts to CW or amplitude-modulated VHF fields: Selective efflux of calcium ions at 16 Hz. *Bioelectromagnetics* 11:349–58.

Selye, H. 1951. The general-adaptation-sydrome. *Ann Rev Med* 2:327–42. doi:10.1146/annurev.me.02.020151.001551.

Sharifian, A., M. Gharavi, P. Pasalar, and O. Aminian. 2009. Effect of extremely low frequency magnetic field on antioxidant activity in plasma and red blood cells in spot welders. *Int. Arch. Occup. Environ. Health.* 82:259–66. doi:10.1007/s00420-008-0332-2.

Shen, Z., J. Song, B. C. Yung, Z. Zhou, A. Wu, and X. Chen. 2018. Emerging strategies of cancer therapy based on ferroptosis. *Adv. Mater.* 30:e1704007. doi:10.1002/adma.v30.12.

Shepherd, S., M. A. P. Lima, E. E. Oliveira, S. M. Sharkh, C. W. Jackson, and P. L. Newland. 2018. Extremely low frequency electromagnetic fields impair the cognitive and motor abilities of honey bees. *Sci. Rep.* 8:7932. doi:10.1038/s41598-018-26185-y.

Sheppard, D. M. W., J. Li, K. B. Henbest, S. R. T. Neil, K. Maeda, J. Storey, E. Schleicher, T. Biskup, R. Rodriguez, S. Weber, et al. 2017. Millitesla magnetic field effects on the photocycle of an animal cryptochrome. *Sci. Rep.* 7:42228. doi:10.1038/srep42228.

Sherrard, R. M., N. Morellini, N. Jourdan, M. El-Esawi, L.-D. Arthaut, C. Niessner, F. Rouyer, A. Klarsfeld, M. Doulazmi, J. Witczak, et al. 2018. Low-intensity electromagnetic fields induce human cryptochrome to modulate intracellular reactive oxygen species. *PLoS Biol.* 16: e2006229. doi:10.1371/journal.pbio.2006229.

Shokrollahi, S., F. Ghanati, and R. H. Sajedi. 2018. Possible role of iron containing proteins in physiological responses of soybean to static magnetic field. *J. Plant Physiol.* 226:163–71. doi:10.1016/j.jplph.2018.04.018.

Shterman, N., B. Kupfer, and C. Moroz. 1991. Comparison of transferrin receptors, iron content and isoferritin profile in normal and malignant human breast cell lines. *Pathobiol* 59:19–25. doi:10.1159/000163611.

Solek, P., L. Majchrowicz, D. Bloniarz, E. Krotoszynska, and M. Koziorowski. 2017. Pulsed or continuous electromagnetic field induce p53/p21-mediated apoptotic signaling pathway in mouse spermatogenic cells in vitro and thus may affect male fertility. *Toxicology* 382:84–92. doi:10.1016/j.tox.2017.03.015.

Somosy, Z., G. Thuroczy, and T. Kubasova, et al. 1991. Effects of modulated and continuous microwave irradiation on the morphology and cell surface negative charge of 3T3 fibroblasts. *Scanning Microsc* 5:1145–1155.

Song, K., S. H. Im, Y. J. Yoon, H. M. Kim, H. J. Lee, G. S. Park, and M. R. Scarfi. 2018. A 60 Hz uniform electromagnetic field

promotes human cell proliferation by decreasing intracellular reactive oxygen species levels. *PLoS ONE* 13:e0199753. doi:10.1371/journal.pone.0199753.

Sullivan, K., A. K. Balin, and R. G. Allen. 2011. Effects of static magnetic fields on the growth of various types of human cells. *Bioelectromagnetics* 32:140–47. doi:10.1002/bem.20624.

Tasset, I., F. J. Medina, I. Jimena, E. Agüera, F. Gascón, M. Feijóo, F. Sánchez-López, E. Luque, J. Peña, R. Drucker-Colín, et al. 2012. Neuroprotective effects of extremely low-frequency electromagnetic fields on a Huntington's disease rat model: Effects on neurotrophic factors and neuronal density. *Neuroscience* 209:54–63. doi:10.1016/j.neuroscience.2012.02.034.

Tattersall, J. E., I. R. Scott, S. J. Wood, J. J. Nettell, M. K. Bevir, Z. Wang, N. P. Somasiri, and X. Chen. 2001. Effects of low intensity radiofrequency electromagnetic fields on electrical activity in rat hippocampal slices. *Brain Res.* 904:43–53. doi:10.1016/s0006-8993(01)02434-9.

Tofani, S., D. Barone, M. Cintorino, M. M. de Santi, A. Ferrara, R. Orlassino, P. Ossola, F. Peroglio, K. Rolfo, and F. Ronchetto. 2001. Static and ELF magnetic fields induce tumor growth inhibition and apoptosis. *Bioelectromagnetics* 22:419–28.

Trowbridge, I. S., R. A. Newman, D. L. Domingo, and C. Sauvage. 1984. Transferrin receptors: Structure and function. *Biochem. Pharmacol.* 33:925–32. doi:10.1016/0006-2952(84)90447-7.

Túnez, I., R. Drucker-Colín, I. Jimena, F. J. Medina, M. D. C. Muñoz, J. Peña, and P. Montilla. 2006. Transcranial magnetic stimulation attenuates cell loss and oxidative damage in the striatum induced in the 3-nitropropionic model of Huntington's disease. *J. Neurochem.* 97:619–30. doi:10.1111/j.1471-4159.2006.03724.x.

Türközer, Z., G. Güler, and N. Seyhan. 2008. Effects of exposure to 50 Hz electric field at different strengths on oxidative stress and antioxidant enzyme activities in the brain tissue of guinea pigs. *Int. J. Radiat. Biol.* 84:581–90. doi:10.1080/09553000802203606.

Valko, M., D. Leibfritz, J. Moncol, M. T. D. Cronin, M. Mazur, and J. Telser. 2007. Free radicals and antioxidants in normal physiological functions and human disease. *Int. J. Biochem. Cell. Biol.* 39:44–84. doi:10.1016/j.biocel.2006.07.001.

Van Huizen, A. V., J. M. Morton, L. J. Kinsey, D. G. Von Kannon, M. A. Saad, and T. R. Birkholz. 2019. Weak magnetic fields alter stem cell-mediated growth. *Sci. Adv* 5:eaau7201. doi:10.1126/sciadv.aax7333.

Vignola, M. B., S. Dávila, D. Cremonezzi, J. C. Simes, J. A. Palma, and V. R. Campana. 2012. Evaluation of inflammatory biomarkers associated with oxidative stress and histological assessment of magnetic therapy on experimental myopathy in rats. *Electromagn. Biol. Med.* 31:320–32. doi:10.3109/15368378.2011.641706.

von der Emde, G. 1999. Active electrolocation of objects in weakly electric fish. *Exp. Biol.* 202:1205–15.

Wang, C. X., I. A. Hilburn, and D.-A. Wu. 2019. Transduction of the geomagnetic field as evidenced from alpha-band activity in the human brain. *eNeuro*, 6 (2): e0483-18 2019 1–23.

Wang, D., L. Zhang, G. Shao, S. Yang, S. Tao, K. Fang, and X. Zhang. 2018a. 6-mT 0-120-Hz magnetic fields differentially affect cellular ATP levels. *Environ. Sci. Pollut. Res. Int.* 25:28237–47. doi:10.1007/s11356-018-2868-3.

Wang, S., J. Luo, Z. Zhang, D. Dong, Y. Shen, Y. Fang, L. Hu, M. Liu, C. Dai, S. Peng, et al. 2018b. Iron and magnetic: New research direction of the ferroptosis-based cancer therapy. *Am. J. Cancer Res.* 8:1933–46.

Wartenberg, M., N. Wirtz, and A. Grob. 2008. Direct current electrical fields induce apoptosis in oral mucosa cancer cells by NADPH oxidase-derived reactive oxygen species. *Bioelectromagnetics* 29:47–54. doi:10.1002/bem.20361.

Wiltschko, R., P. Thalau, D. Gehring, C. Nießner, T. Ritz, and W. Wiltschko. 2015. Magnetoreception in birds: The effect of radio-frequency fields. *J. R. Soc. Interface* 12:pii: 20141103. doi:10.1098/rsif.2014.1103.

Wolf, F. I., A. Torsello, B. Tedesco, S. Fasanella, A. Boninsegna, M. D'Ascenzo, C. Grassi, G. B. Azzena, and A. Cittadini. 2005. 50-Hz extremely low frequency electromagnetic fields enhance cell proliferation and DNA damage: Possible involvement of a redox mechanism. *Biochim. Biophys. Acta.* 1743:120–29. doi:10.1016/j.bbamcr.2004.09.005.

Wolke, S., U. Neibig, R. Elsner, F. Gollnick, and R. Meyer. 1996. Calcium homeostasis of isolated heart muscle cells exposed to pulsed high-frequency electromagnetic fields. *Bioelectromagnetics* 17:144–53. doi:10.1002/(SICI)1521-186X(1996)17:2<144::AID-BEM9>3.0.CO;2-3.

Wu, S. X., Y. Q. Xu, and G. Q. Di. 2016. Influence of environmental static electric field on antioxidant enzymes activities in hepatocytes of mice. Genet. *Mol. Res.* 15. doi:10.4238/gmr.15038800.

Yakymenko, I., O. Tsybulin, E. Sidorik, D. Henshel, O. Kyrylenko, and S. Kyrylenko. 2016. Oxidative mechanisms of biological activity of low-intensity radiofrequency radiation. *Electromagn. Biol. Med.* 35:186–202. doi:10.3109/15368378.2015.1043557.

Yang, M. L., and Z. M. Ye. 2015. Extremely low frequency electromagnetic field induces apoptosis of osteosarcoma cells via oxidative stress. *Zhejiang Da Xue Xue Bao Yi Xue Ban* 44:323–28. [Article in Chinese].

Yitzhak, N.-M., R. Hareuveny, S. Kandel, and R. Ruppin. 2012. Time dependence of 50 Hz magnetic fields in apartment buildings with indoor transformer stations. *Radiat. Prot. Dosimetry.* 149:191–95. doi:10.1093/rpd/ncr226.

Yokus, B., D. U. Cakir, M. Z. Akdag, C. Sert, and N. Mete. 2005. Oxidative DNA damage in rats exposed to extremely low frequency electromagnetic fields. *Free Radic. Res.* 39:317–23. doi:10.1080/10715760500043603.

Yokus, B., M. Z. Akdag, S. Dasdag, D. U. Cakir, and M. Kizil. 2008. Extremely low frequency magnetic fields cause oxidative DNA damage in rats. *Int. J. Radiat. Biol.* 84:789–95. doi:10.1080/09553000802348203.

Zeni, O., M. Simkó, and M. R. Scarfi. 2017. Cellular response to ELF-MF and heat: Evidence for a common involvement of heat shock proteins? *Front Public Health* 18:280.

Zhang, D., Y. Zhang, B. Zhu, H. Zhang, Y. Sun, and C. Sun. 2017. Resveratrol may reverse the effects of long-term occupational exposure to electromagnetic fields on workers of a power plant. *Oncotarget* 8:47497–506. doi:10.18632/oncotarget.17668.

Zhang, J., C. Ding, X. Meng, and P. Shang. 2018. Nitric oxide modulates the responses of osteoclast formation to static magnetic fields. *Electromagn. Biol. Med.* 37:23–34. doi:10.1080/15368378.2017.1414057.

Zimmerman, J. W., M. J. Pennison, I. Brezovich, N. Yi, C. T. Yang, R. Ramaker, D. Absher, R. M. Myers, N. Kuster, F. P. Costa, et al. 2012. Cancer cell proliferation is inhibited by specific modulation frequencies. *Br. J. Cancer* 106:307–13. doi:10.1038/bjc.2011.523.

Zmyslony, M., E. Rajkowska, P. Mamrot, P. Politanski, and J. Jajte. 2004. The effect of weak 50 Hz magnetic fields on the number of free oxygen radicals in rat lymphocytes in vitro. *Bioelectromagnetics* 25:607–12. doi:10.1002/bem.20045.

SUPPLEMENTARY MATERIAL

Literature on free radical generation after expsore to static and extremely-low-frequency electromagnetic fields (as of July 2019)

Two types of free radicals can be generated: reactive oxygen species (ROS) ans reactive nitrogen species (RNS). Activity in the mitochondrial electron transport chain leads to the production of superoxide radical anion ($O_2^{\bullet -}$) which can be converted to hydrogen peroxide (H_2O_2) by various forms of superoxide dismutate (SOD). H_2O_2 can be degraded by catalase (CAT) into water and oxygen or converted by the iron-dependent Fenton reaction into the potent hydroxyl radical ($OH^{\bullet}$). In the cytoplasm, nitric oxide ($NO^{\bullet}$) is generated by various forms of nitric oxide synthase (NOS) by conversion of L-arginine to L-citrulline. $NO^{\bullet}$ reacts with $O_2^{\bullet -}$ to generate the potent oxidant peroxynitrite ($ONOO^-$). $O_2^{\bullet -}$ can also be produced by NOS by transfer of electron from NADPH to O_2. Other enzymatic processes, such as cytochrome P_{450}, also generate ROS in normal cellular activities.

Major anti-oxidative processes in cells include catalase/peroxidase that converts $O_2^{\bullet -}$ to H_2O and O_2. In the process, glutathione (GSH) is oxidized to glutathione disulfide (GSSG). GSSG is reduced back to GSH by the enzyme glutathione reductase with the conversion of NADPH to NADP. GSH and NADPH are the most common electron donors participated in cellular anti-oxidation processes. $ONOO^-$ is decomposed by peroxiredoxin and glutathione peroxidase into less potent nitrogen free radicals ($NO_3^{\bullet}/NO_2^{\bullet}$).

ROS react with cellular macromolecules, e.g., DNA, protein, and lipid. The most common form of DNA oxidative damage is the formation of hydroxylated bases. 8-hydroxy-2'-deoxyguanosine (8-OHdG) is generally used an index of oxidative DNA damage. ROS react with lipids to produce lipid peroxyl radicals and lipid hydroperoxides. Lipid peroxyl can subsequently form malondialdehyde (MDA), which is commonly used as an index of oxidative lipid damage. Lipid radicals can diffuse through membrane leading to protein oxidation and formation of DNA-MDA adduct. Oxidative lipid damages affect the structure and function of cell membrane. ROS attack proteins directly and indirectly. Protein carbonyl is a form of protein oxidative damage. Changes in protein structure lead to alteration in enzymatic activities, particularly, damage to membrane transport proteins leads to ionic imbalance such as intracellular concentrations of calcium and potassium. Oxidative stress could also cause changes in regulation of transcription factors in cells, e.g., the Nrf2 antioxidant pathway.

More than 200 papers have been published on effects of *in vitro* and in *vivo* exposure to static and extremely–low frequency electromagnetic fields on various aspects of the free radical processes in living organisms. Table 1 is a summary of these papers (as of April 2019). (It is inevitable that some relevant studies were omitted in the following literature survey.)

Table I. Summary of papers on the effects of ELF-EMF on oxidative processes in cells and animals. (* Study reported no significant effect on oxidative processes; ↑ increase; ↓ decrease; Ø no significant effect; MF= magnetic field; EF = electric field; CAT= catalase; GSH= glutathione; GST = glutathione S-transferase; GPx = glutathione peroxidase; NOS= nitric oxide synthase; MPO= myeloperoxidase; ROS = reactive oxygen species; SOD= superoxide dismutase) In some studies, the term EMF (electromagnetic field) was used. The authors may mean magnetic field or a combination of magnetic and electric fields, since most exposure systems emit both fields when not properly shielded and grounded. On the other hand, fields labelled as magnetic field in some studies may contain also electric component.,

			Oxidative damages (DNA, protein, lipid)	*ROS ($O_2^{\cdot-}$, OH, H_2O_2, NO)*	*NOS*	*Antioxidative processes (SOD, CAT/ peroxidase, GSH, GPx)*	*Effect of antioxidants/ scavengers*	*Remarks*
Akan et al. (2010)	Activated THP-1 cells (human monocytic leukemia cells)	50-Hz EMF, 1 mT, 4-6 h		↑NO	↓ iNOS			↑cGMP
Akdag et al. (2007)	Sprague-Dawley rat serum in vivo	50-Hz MF, 0.1 and 0.5 mT, 2 h/day, 10 months		↓NO				
Akdag et al. (2010)	Sprague-Dawley rat brain in vivo	50-Hz MF, 0.1 and 0.5 mT, 2 h/day, 10 months	↑ lipid peroxidation			↓ CAT		↑ total oxidant status, ↓ total anti-oxidative capacity
Akdag et al. (2013a)	Sprague-Dawley rat brain in vivo	50-Hz MF, 0.1 and 0.5 mT, 2 h/day, 10 months	↑ protein carboxylation ↑ lipid peroxidation					
*Akdag et al. (2013b)	Sprague-Dawley rat testes in vivo	50-Hz MF, 0.1 and 0.5 mT, 2 h/day, 10 months	Ø lipid peroxidation			Ø CAT		No change in total oxidant status and total anti-oxidative capacity
Akpinar et al. (2012)	Wister rat brain and retina in vivo	50-Hz EF, 12 and 18 kV/m, 1 h/day, 14 days	↑ lipid peroxidation					↑ total oxidant status, ↓ total anti-oxidative capacity
Akpinar et al. (2016)	Wister rat brain in vivo	50-Hz EF, 12kV/m, 1 h/day,	↑lipid peroxidation in Po, ↓in PP (cf. Pr and Po)					

		prenatal (Pr), postnatal (Po, 30 days), and prenatal + postnatal (PP)	↓ protein carboxylation in PP					
Aksen et al. (2006)	Wister rat uterus and ovary in vivo	50-Hz EMF, 1 mT, 3 h/day, 50 or 100 days	↑ lipid peroxidation					
*Alcaraz et al. (2014)	Micronucleated cells induced by EMF in bone morrow of mouse	50-Hz EMF, 0.2 mT, for 7, 14, 21, or 28 days					Effect not blocked by 4 types of antioxidant	
Amara et al. (2009)	Male Wistar rat, frontal crtex and hippocampus	Static MF, 128 mT, 1 h/day, 30 days	Ø DNA			↓ GPx, CuZn-SOD and CAT in frontal cortex ; ↓ CuZn-SOD and Mn-SOD in hippocampus		
Amara et al. (2011)	Male Wistar rat, frontal crtex	Static MF, 128 mT, 1 h/day, 30 days and cadmium treatment	Synergistic with cadmium in ↑ lipid peroxidation			Synergistic with cadmium in ↓ SOD and glutathione		
Ansari et al. (2016)	NMRI mice	50-Hz MF, 0.5 mT, 2 h or 2 h/day for 2 weeks		↑ NO				Blocked effect of L-NAME, a NOS inhibitor, long ter exposure reversed depressive disorder in mice
Asghar et al. (2016)	Soybean seeds and seedlings	50-Hz MF, 50, 75, or 100 mT for 3 or 5 min	↑ lipid peroxidation at 50 mT for 3 min (not at other exposure conditions)	↑H_2O_2 at 50 and 100 mT for 3 min		↑ SOD at 75 mT for 3 and 5 min; ↑CAT/peroxidase at 50, 75 and 100 mT for 3 min;		↑ ascorbic acid
Ayşe et al. (2010)	K562 cells, in vitro	50-Hz EMF, 5 mT, 1 h or 1 h/day for 4 days		↑ $O_2^{\cdot-}$				Effect disappeared at 2 h post-exposure, no interaction with hemin
Bawin et al. (1996)	Electrical activity of rat	1-Hz MF, 0.56 and 0.056 mT, 10 min			Effect blocked			60-Hz MF has no

	hippocampal slices				by NOS inhibitor			significant effect
Bediz et al. (2006)	Sprague-Dawley rat blood and brain in vivo	50-Hz EMF, 0.005 mT, 5 min every other day for 6 months	↑ lipid peroxidation			↓GSH		Effect attenuated by zinc
Belova et al. (2010)	Activated mouse peritoneal neutrophils	Combined magnetic field (CMF) tuned to calcium ion (DC 40.6 μT, AC 74.7 μT at 31 Hz): pulsed MF (225 μs, 20 pulses packet at 15 Hz, 1500 μT); up to 30 min exposure		CMF ↓ ROS, pulsed MF ↑ ROS				
Benassi et al. (2016)	SH-SY5Y cells (human used to study Parkinson's disease)	50-Hz MF, 1 mT, 6-72 h	↑ protein carboxylation					
Buczyński et al. (2005)	Human blood platelets	1 kHz MF, 0.5 mT, 30, 60 or 90 min	↑ lipid peroxidation					Effect observed only after 30 and 90 min exposure, not at 60 min
Budziosz et al. (2018)	Male Wistar rats, frontal cortex, hippocampus, brainstem, hypothalamus, striatum, cerebellum	50-HZ EMF, 22 h/day, 28 days, 4.4 pT	Ø lipid peroxidation	Ø total oxidant status		Changes (↑ and ↓) in SOD, CAT and glutathione-related enzymes depended on barin region		
Buldak et al. (2012)	AT478 murine squamous carcinoma cells	EMF 50-Hz, 1 mT, 16 min	↓ lipid peroxidation			↑SOD ↑GPx		MF lessens oxidative effects of cisplatin

Calabro et al. (2013)	SH-SY5Y cells	Static MF, 2.2 mT, 24 h		↑ ROS production				
Calcabrini et al. (2017)	Human keratinocyte (NCTC 2544)	50 Hz MF, 0.025 – 0.2 mT, 1 h	↑ lipid peroxidation at 0.05 and 0.1 mT	↑ ROS at 0.05 and 0.1 mT		↓ SOD and ↑GSH at 0.05 and 0.1 mT		↑ ROS blocked by the iron chelator o-phenanthroline
Calota et al. (2006)	Human blood serum	50-Hz EF, 5, 7.5 10, 15, 20 kV/m, 1-2 h		↓ ROS production				
Calota et al. (2007)	Human blood serum	50-Hz MF, 0.357, 0.596, 1.788, 2.384 mT, 1-2 h		↑ ROS production, enhanced by $FeCl_2$ and H_2O_2				
Canseven et al. (2008)	Guinea pig, liver and heart tissues	50-Hz MF, 1, 2, or 3 mT, 4 or 8 h/day for 5 days	↑ and ↓ in lipid peroxidation	↑ and ↓ in NO		MPO (↑ or ↓) depending on exposure condition (duration and intensity) and tissue studied; ↑ and ↓ in GSH		
Chen et al. (2014)	Mouse embryonic fibroblast	50-Hz MF, 2 mT, 0.5, 2, 6, 12, 24 h		↑ ROS				
Cheun et al. (2007)	Canine kidney MDCK cells	60-Hz MF, 1.4 mT, seconds		MF affected ROS kinetics when H_2O_2 was added to cells.				
Chu et al. (2011)	Mouse cerebellum in vitro	60-Hz MF, 2.3 mT, 3 h	↑ lipid peroxidation	↑OH		↑SOD Ø GPx		
Chung et al. (2015)	Rat brain in vivo	60-Hz MF, 2.0 mT, 2 or 5 days		↑NO in striatum, thalamus and hippocampus				
Cichon et al. (2017a)	Post-stroke patients	40-Hz, 7 mT for 15 min/day for 4weeks (5 days a week)				↑ SOD and CAT in hemolysates		Ø total antioxidant status in plasma; exposed patients showed better improvement in functional and mental status

Cichon et al. (2017b)	Post-stroke patients	40-Hz, 7 mT for 15 min/day for 4weeks (5 days a week)		↑ 3-nitrotyrosine ↑ nitrate/nitrite ratio				ELF-EMF promotes recovery of post-stroke patients
Cichon et al. (2018a)	Post-stroke patients, blood mRNA	Rectangular, bipolar waves, 5 mT, 40 Hz, 15 min/session, 10 sessions in 14 days,						↑ CAT, SOD1, SOD2, GPx1, GPx4 mRNA
Cichon et al. (2018b)	Post-stroke patients, blood	Rectangular, bipolar waves, 5 mT, 40 Hz, 15 min/session, 20 sessions in 20 days,	↓ lipid peroxidation ↓ protein carboxlation					Improved psychophysical abilities of patients
Ciejka et al. (2009)	Sprague-Dawley rats in vivo (plasma)	40-Hz MF, 7 mT, 30 or 60 min per day for 14 days						Repeated 30-min and 60-min exposure increased and decreased plasma antioxidant activity, respectively.
Ciejka et al. (2010)	Sprague-Dawley rats in vivo (muscle)	40-Hz MF, 7 mT, 30 or 60 min per day for 14 days						Both exposures caused an increase in -SH and decrease in proteins in muscle
Ciejka et al. (2011)	Sprague-Dawley rats in vivo (brain)	40-Hz MF, 7 mT, 30 or 60 min per day for 14 days	↑ lipid peroxidation in brain of 30-min per day exposed rats					Rats exposed for 60 min per day, 14 days showed increases in -SH and proteins in brain (adaptation).

Ciejka et al. (2014)	Sprague-Dawley rats in vivo (muscle)	40-Hz MF, 7 mT, 30 or 60 min per day for 14 days				↑GSH		
Coballase-Urrutia et al. (2018)	Restraint Wistar rats	Static MF, 0.8 mT, 30, 60, 240 min/day, 5 days						Attenuated restaint stress-induced increases in NO and MDA and decreases in SOD and GSH
Consales et al. (2018)	SH-SY5Y human neuroblastoma cells and mouse primary cortical neurons	50-Hz MF. 1 mT, 24, 48 or 72 h	↑ $O_2^{\cdot-}$, H_2O_2,					Some ROS produced by mitochondria; affected by microRNA (miR-34)
*Consales et al. (2019)	SH-SY5Y human neuroblastoma cells (wild type and two mutants)	50-Hz MF, 1 mT, 24-72 h	Ø $O_2^{\cdot-}$, H_2O_2,					↓ iron cotent and ron-gene expression in a mutant cell-type; Ø viability and proliferation
Coskun et al. (2009)	Guinea pig in vivo-plasma, brain, and liver	50-Hz MF, 1.5 mT, continuous (C) (4h/day) or intermittent (I) (2 h on/2 h off/2h on) for 4 days	Plasma: I ↑ lipid peroxidation Brain: C, ↓ lipid peroxidation Liver: C, I ↑lipid peroxidation	Plasma: C, I ↑ NO		MPO: Plasma C ↑, Brain C, I ↑, Liver C, I ↓ GSH: C ↑ I ↓ in brain		
Cui et al. (2012)	C57BL/6 mice in vivo, striatum and hippocampus	50-Hz MF, 1 or 0.1 mT, 4h/day, 12 days	↑ lipid peroxidation in 1 mT group			↓ CAT and ↓GSH in 1 mT group		↓Total antioxidant capability in 1 mT group
*de Groot et al. (2014)	Normal and chemically-stressed PC12 cells	50-Hz EMF, 30 min or 48 h, up to 1 mT		No effect on ROS production as measured by H_2-DCFDA				
* De Mattei et	Bovine articular	75-Hz EMF 1.3 ms pulses,		Ø NO				Pulses enhanced Interleukin-

al. (2003)	cartilage explants	2.3 mT peak, 24 h						1β–induced NO production
De Nicola et al. (2006)	U937 cells	Static MF, 6 mT, 2 h; 50-Hz MF, 0.07-0.1 mT, 2 h		↑ ROS		↓GSH		Decreased apoptosis
Deng B. et al. (2014)	Rat primary cerebral cortical neurons	Electromagnetic pulses (peak 400 KV/m, width 350 ns, 0.5 pps, I Hz)	↑ lipid peroxidation			↓SOD		Decreased cell viability observed, effects antagonized by sevoflurane
Deng Y. et al. (2013)	SPF Kunming mouse in vivo, serum and brain	50-Hz MF, 2 mT, 4h/day, 8 weeks	↑ lipid peroxidation			↓SOD		No interaction with aluminum
Di et al. (2012)	Human preosteoclast FLG29.1 cells	Large gradient high magnetic fields (12 T, -1370 T^2/m; 12 T, 1370 T^2/m), 72 h		↓ NO				
*Di Loreto et al. (2009)	Rat cortical neurons	50-Hz MF, 0.1 or 1 mT, 7 days	Ø lipid peroxidation	Ø total ROS		Ø GSH		↑ cell viability, ↓ apoptosis
Dinčić et al. (2018)	Wistae albino rats	Static magnetic field, 1 mT, 50 days	↑ lipid peroxidation			↓ synaptosomal CAT depending on oritentation of static MF		↑ ATPase and AchE in synaptosomes
Ding et al. (2004)	Human leukemia HL-60 cells	60-Hz MF, 5 mT, 24 h						Enhanced apoptotic effect of H_2O_2
Djordjevic et al. (2017)	Wistar male rats	50-Hz MF, 10 mT, 7 days, 24 h/day		↑ $O_2^{\cdot-}$ *and* NO; Ø peroxynitrite (ONOO-) in hypothalamus				
Dornelles et al. (2017)	Human peripheral mononuclear cells with different polymorphism at Vali1la-MnSOD gene	Static magnetic field, 5 mT; 0,1,3,6 h	↑ and Ø lipid peroxidation, ↑ and ↓ protein carboxylation	↑, ↓ and Ø ROS		↑, ↓ and Ø in SOD1, SOD2, GPX, CAT		Response depended on genetic makeup of the cells

Duan Y. et al. (2013)	ICR mouse, Serum and hippocampus	50-Hz MF, 8 mT, 4 h/day, 28 days	↑ lipid peroxidation	↑NO	↑NOS	↓SOD ↓ CAT ↓GPx		Effects reversed by lotus seedpot procyanidins
*Duan W. et al. (2015)	Mouse spermatocyte-devrived GC-2 cells	50-Hz EMF, 1, 2, or 3 mT, 5-min on 10-min off, 24 h	Ø oxidative DNA base damage					
Duong and Kim (2016)	Human microglial HMO6	50-Hz EMF, 1 mT, 4 h						EMF exposure decreased ROS induced by oxygen-glucose deprivation.
Ehnert et al. (2017)	Human osteoblasts	Pulsed EMF, 16-Hz, 6-282 μT; 7 min or 7min/day (>3 days)		Single exposure ↑ ROS; Repeated exposure ↓ ROS; mainly $O_2^{\cdot-}$ and H_2O_2		↑GPX3, SOD2, CAT, GSR	Effects of EMF blocked by $O_2^{\cdot-}$ and H_2O_2 scavengers	EMF promotes osteoblast differentiation via free radicals
Emre et al. (2011)	Wistar rat in vivo, liver	Pulsed EMF (0.5 ms rise time, 9.5 ms fall time) EF 0.6 V/m, MF 1.5 mT, each frequency train of 1 Hz, 10 Hz, 20 Hz and 40 Hz was given for 4-min and with 1-min interval between each frequency (together 20 min.); on each day, three exposure cycles performed (1 h), 1 h per day for 30 days	↑ lipid peroxidation			↑SOD		No effect on apotosis, decreased necrosis.
Erdal et al. (2008)	Male and female	50-Hz MF, 1 mT, 4/day, 45 days	Ø lipid peroxidation					Increased 3-nitrotyrosine (oxidative/

	Wistar rat in vivo, liver							nitrosative stress) in liver of female rats.
Errico Provenzano et al. (2018)	NB4 cells (human acute promyelocytic leukemia)	50 Hz MF, 2 mT, 8, 16, 24 h		↑ROS				
Falone et al. (2007)	Human neuroblastoma cells SH-SY5Y	59-Hz MF, 1 mT, 96-192 h		Ø ROS		Ø SOD, CAT ↑ GST, GPx 5x ↑ reduced/total GSH ratio		Increased cell viability; Ø cell circle, apoptosis and DNA damage, but enhanced these effects induced by H_2O_2.
Falone et al. (2008)	Female Sprague-Dawley rat in vivo, 3- and 19-month old, brain cortex	50-Hz MF, 0.1 mT, 10 days				↑SOD_2 in young rats; ↓ catalase and GPx in old rats		↓Glutathione reductase in old and young rats, ↓ glutathione-s-transferase in old rats: old and young rats responded differently.
Falone et al. (2016)	Human drug-resistant neuroblastoma SK-N-BE(2) cells	72-Hz pulsed EMF, 1.3 ms pulse duration, 2 mT, 15 min, 3 times over 5 days						Pulsed EMF increased MnSOD-based antioxidant protection and reduced ROS production induced by H_2O_2 .
Falone et al. (2017)	SH-SY5Y human neuroblastoma cells	50-Hz MF, 0.1 or 1 mT, 5 and 10 days	↓ protein carboxylation and DNA oxidation			↑ GPx/SOD and catalase/SOD ratios, i.e., increase antioxidating defense; ↑ GPx activity		Protects cell death by H_2O_2, ↑ Nrf2 activity
Feng et al. (2016a)	Human amniotic epithelial cells	50-HZ MF, 0.4 mT, 5, 15, 30 or 60 min		↑ ROS			MF-induced mitochondrial permeability transition	

							blocked by NAC	
Feng et al. (2016b)	Human amniotic epithelial cells	50-HZ MF, 0.1, 0.2, or 0.4 mT, 5, 15, 30, or 60 min		↑ ROS				↑ total ROS at 0.2 mT and higher, ↑NADPH oxidase-produced superoxide
Feng et al. (2016c)	Human amniotic epithelial cells	50-Hz MF, 0.2-2 mT, 30, 60, 120 min		↑ mitochondrial ROS				↑ ROS led to activation of Akt and anti-apoptotic effect
Fernie & Bird (2001)	American kestrel	60-Hz EMF, 30 μT,10 kV/m, 91 days, 23.5 h/day						Decreased plasma carotenoids
Fiorani et al. (1997)	Rabbit red blood cells	50-Hz MF, 0.2-0.5 mT, 90 min in the presence of an oxygen-generating system (Fe(II)/ascorbate)						Enhanced GSH reduction and hemoglobin oxidation caused by Fe(II)/ascorbate at 0.5 mT
Fitzsimmons et al. (2008)	Human chondrocyte	Pulsed electric field, EF in culture medium 0.2 mV/cm, 30 min		↑NO				↑cGMP, calcium involved
Frahm et al. (2006)	Mouse bone-marrow derived macrophage	50-Hz MF, 0.05, 0.1, 0.5, 1.0 mT, 45 min		↑ROS				
Frahm et al. (2010)	Mouse bone-marrow derived macrophage	50-Hz MF, 1.0 mT, 45 min		↑ROS				Activated enzymes (NAD(P)H oxidases) and proteins involved in redox homeostasis

Garip and Akan (2010)	K562 human leukemia cells, normal or treated with H_2O_2	50-Hz EMF 1 mT, 3 h		↑ROS				Decreased and increased apoptosis in untreated and H_2O_2-treated cells, respectively.
Ghodbane et al. (2011a)	Wistar male rat in vivo, plasma	Static MF, 128 mT, 1 h/day, 5 days	Ø lipid peroxidation			↑ GPx		Decreased vitamin A and E levels, effects blocked by selenium
Ghodbane et al. (2011b)	Wistar male rat in vivo, liver, kidney, muscle , brain	Static MF, 128 mT, 1 h/day, 5 days				↑ SOD in liver, ↓ GPx in kidney and muscle, ↑ GSH in liver		Selenium reversed GPx effect in kidney and muscle
Ghodbane et al. (2014)	Wistar male rat in vivo, plasma	Static MF, 128 mT, 1 h/day, 5 days					Vitamin E blocked static MF effects on blood glucose and liver glycogen	
Ghodbane et al. (2015a)	Wistar male rat in vivo, brain and liver	Static MF, 128 mT, 1 h/day, 5 days	Ø lipid peroxidation in brain and liver			↑ CAT in liver	selenium and vitamin E reversed liver catalase effect.	↑ apoptosis in liver through a mitochondrial capase-independent pathway
Ghodbane et al. (2015b)	Wistar male rat in vivo, kidney and muscle	Static MF, 128 mT, 1 h/day, 5 days	↑ lipid peroxidation in kidney			↑ CAT in kidney	vitamin E reversed lipid peroxidation effect.	Selenium reversed ↑ lipid peroxidation and CAT effects in kidney
*Giorgi et al. (2014)	Human neuroblastoma BE(2) cells	Bipolar pulsed square wave MF, 50 Hz, 1 mT, up to 72 h	MF did not affect H_2O_2-induced DNA double strand break.					
Giorgi et al. (2017)	Human neuroblastoma BE(2) cells	Bipolar pulsed square wave MF, 50 Hz, 1 mT, (average	MF ↑DNA methylation with 24 h exposure (not with 48 h)					Oxidative stre (300 μM H_2O_2) decreased

		rate of change in MF 3.3 T/s) 24 or 48 h						DNA methylation compared to PMF alone
Glinka et al. (2013)	Male Sprague-Dawley rat in vivo, blood serum and liver	40-Hz MF, 10 mT, 30 min /day for 6, 10, or 14 days	↓ lipid peroxidation in liver of 6-day exposure			↑SOD-Mn in serum only in 6 day exposure, ↓SOD-Mn in liver in 14-day exposure. No effect on SOD-ZnCu ↑ GPx in serum in 10- and 14-day exposure		↑glutathione s-transferase in liver of 6-day exposure
Glinka et al. (2018)	Mouse fibroblasts	Static magnetic field, 0.1-0.7 T, 72 h	Ø lipid peroxidation			↓ SOD and GPx		
Gok et al (2016)	Wistar rat in vivo, brain and retina	50-Hz EF, 12 kV/m, I h/day during prenatal, postnatal, and prenatal + postnatal period	↑ lipid peroxidation in brain and retina of exposed animals					Prolonged visual evoked potentials were observed in exposed animals.
Goraca et al. (2010)	Male Wistar rat in vivo, heart and plasma	40-Hz MF, 7 mT, 30 or 60 min/day, 14 days	↑ lipid peroxidation in heart in 30 and 60 min/day exposure	↑ H_2O_2 in heart in 30 and 60 min/day exposure		↓ GSH in heart 60min/day		Total free – SH decreased in heart of 60 min/day, decreased reducing capability in plasma of 60 min/day
Güler et al (2008)	Male guinea pig in vivo, liver	50-Hz EF, 12 kV/m, 8 h/day, 7 days	↑ lipid peroxidation	↑NO		↓SOD ↓ GPx ↓ MPO	Blocked by NAC	
*Güler et al (2009a)	Male guinea pig in vivo, plasma	50-Hz EF, 12 kV/m, 8 h/day, 7 days	Ø oxidative protein damage					
Güler et al (2009b)	Male guinea pig in vivo, lung	50-Hz EF, 12 kV/m, 8 h/day, 7 days	↑ protein carboxylation Ø lipid peroxidation	Ø NO				
Hajipour Verdom et al. (2018)	Human MCF-7 breast cancer cels and HFF normal fibroblasts	Static magnetic field 10 mT, 24 and 48 h		↑ ROS		↑ GSH in HFF cells		Decreased viability and differentiation in both cell types; Synergistic with doxorubicin

Hajnorouzi et al. (2011)	Maize seedling	Combination of geomagnetic field (47 μT) and perpendicular 10-kHz MF (22 μT), 5 h/day for 4 days				↓SOD		↑Total antioxidant capacity, faster growth of seedlings, decrease iron increased growth
Hanini et al. (2017)	Mutant Pseudomonas aeruginosa without Mn- and Fe-SOD	Static magnetic field, 200 mT	↑ lipid peroxidation			↑ SOD, CAT, peroxidases		Wide type bacteria less responsive to the field
*Harakawa et al. (2005)	Sprague-Dawley rat in vivo, plasma	50-Hz EF, 17.5 kV/m, 15 min/day, 7 days	Ø lipid peroxidation (↓ in oxidatively stressed rats)					No effect on total antioxidant activity
Hashish et al., (2008)	Male Swiss (BALB/c) mouse in vivo, liver	Static MF (+/- 2.9 μT), or 50-Hz MF 1.4 mT, 30 days	↑ lipid peroxidation			↓GSH in ELF-MF exposure only		↑glutathione s-transferase
Henrykowska et al. (2009)	Human blood platelet	50-Hz MF, 10 mT, 15 min (sinusoidal, triangular, or rectangular)	↑ lipid peroxidation	↑ ROS		↓SOD-1 ↑catalase		Effects not wave-shape dependent
*Hong et al. (2012)	Human breast epithelial cells (MCF10A)	60-Hz MF, 1 mT, 4 h		Ø ROS level		Ø SOD Ø GSH		
Hosseinabadi and Khanjani (2019)	Power-plant workers, serum	Chronic ELF-EMF average electric and magnetic field of 4.09 V/m and 16.27 μT						↑ SOD, CAT, GPx, and lipid peroxiation on serum corealted with prevalence of musculoskeletal disorders
Höytö et al. (2017)	Human SH-SY5Y	50-Hz MF, 0.1 mT, 24 h		↑ cytosolic $O_2^{\cdot-}$ production; ↓ mitochondrial $O_2^{\cdot-}$ production				

	neuroblastoma cells							
Hu et al., (2016)	3xTG mouse. hippocampus	50-Hz MF, 0.5 mT, 20 h/day for three months		↑ ROS				Decreased cognitive deficits, decreaed apoptosis; decreased molecules involved in oxidative stress
Jajte et al. (2001)	Rat lymphocyte	50-Hz MF, 7 mT, 3 h	DNA strand breaks				DNA strand breaks induced by MF and $FeCl_2$ blocked by melatonin.	
Jajte et al. (2002)	Rat lymphocyte	Static MF, 7 mT, 3 h	↑ lipid peroxidation with MF + $FeCl_2$					
Jajte et al. (2003)	Rat lymphocyte	Static MF, 7 mT, 3 h	↑ lipid peroxidation with MF + $FeCl_2$				Effect blocked by melatonin and vitamin E	
Jelenković et al. (2006)	Male Wistar rat in vivo, different brain regions	50-Hz MF, 0.5 mT, 7 days	↑ lipid peroxidation in basal forebrain only	↑ $O_2^{\cdot-}$ ↑ NO		↑ SOD in basal forebrain only		Different brain regions responded differently.
Jeong et al. (2006)	Male ICR mouse in vivo, brain and spinal cord	60-Hz MF, 2 mT, 48 h		↑NO	Ø nNOS, eNOS, iNOS			Hyperalgesia observed, blocked by Ca^{2+} channel blocker
*Jin et al. (2015)	Human lung epithelial L132 cell	60-Hz MF, 1 or 2 mT, 9 h						MF did not affect H_2O_2-induced G2/M-arrested or aneuploid cells.
*Jin et al. (2012)	Mouse embryonic fibroblast NIH3T3 and human lung fibroblast WI-38 cells	60-Hz MF, I mT, 4 h						MF did not affect H_2O_2-induced micronucleus formation.

*Jin et al. (2014)	Mouse embryonic fibroblast NIH3T3, human lung fibroblast WI-38, human lung epithelial L132, and human mammary epithelial MCF10A cells	60-Hz MF,1 mT, 4 or 16 h						MF did not affect H_2O_2-induced DNA strand breaks.
Jouni et al. (2012)	Broad bean (Vicia faba L.)	Static MF, 15 mT, 8 h/day, 8 days	↑ lipid peroxidation			↑SOD ↓ CAT and peroxidase		
Kamalipooya et al. (2017)	Human cervicle cancer (HeLa) Cell, human fibroblasts	Static MF; 7, 10-16 mT, 24 or 48 h	Synergistic ↑ lipid peroxidation in cisplatin-treated cancer cells	Synergistic ↑ ROS in cisplatin-treated cancer cells				Generally, no effect on normal fibroblast cells; 10 mT caused highest effects in cancer cells
Kantar Gok et al. (2014)	Male Wistar rat in vivo, brain	50-Hz EF, 12 or 18 kV/m for 2 or 4 weeks, 1 h/day	↑ protein carboxylation in 18 kV/m 2 wk and 12 and 18 kV/m 4 wk ↑ lipid peroxidation in all exposed groups					
Karimi et al. (2019)	Male Wistar rats	50-Hz EMF, 1,100. 500, 2000 μT, 2h/day 60 days	↑ lipid peroxidation	↑total thio molecules, ↑ total oxidant staus		↑ total antioxidant activity		Rats showed improved memory retention.
Kavaliers et al. (1998)	Land snail (Cepaea nemoralis) in vivo	60-Hz MF, 0.141 mT, 15 min		↑NO (possible)				MF attenuated opioid-induced analgesia by increasing NO activity
*Kesari et al. (2015)	Human neuroblastoma SH-SY5Y cells	50-Hz MF, 0.1 mT, 24 h	Ø lipid peroxidation	Ø ROS change at 15, 30, and 45 days after exposure				

Kesari et al. (2016)	Human neuroblastoma SH-SY5Y cells and rat C6 glioma cells, cells treated with menadione	50-Hz MF, 10 or 30 μT, 24 h		↑ $O_2^{\cdot-}$ cytosolic and mitochondrial in C6 cells				Increased micronucleus in SH-SY5Y cells at 30 μT
Khadir et al. (1999)	Human neutrophils simulated by phorbol 12-myristate13-acetate	60-Hz MF, 22 mT, 10 min		↑ $O_2^{\cdot-}$				
Kim et al. (2017)	RAW 264.7 macrophage	60-Hz MF, 0.8 mT, up to 20 h		↑NO				Decreased effectiveness of antioxidant; increased macrophage activation
*Kimsa-Dudek et al (2018)	Human dermal fibroblast	Static magnetic field,,0.65T, 24 h		Ø ROS				Changes in antioxidant defense system – related gene expression; Attenuate floride-induced changes in antioxidant defense system gene expression
Koh et al. (2008)	Human prostate cancer cells (DU145, PC3, and LNCaP)	60-Hz MF, 1 mT, 6, 24, 48, 72 h		↑ H_2O_2			Blocked by NAC	Apoptosis and cell cycle arrest observed.
Koyama et al. (2004)	pTN89 plasmids	60-Hz MF, 5 mT, 4 h						MF potentiated H_2O_2-induced mutation

Koyama et al. (2008)	Human glioblastoma A172 cell	60-Hz MF, 5 mT, 2, 4, 8, 16, or 24 h						MF potentiated H_2O_2-induced increase in apurinic/apyrimidinic sites (DNA lesion)
Kthiri et al. (2019)	Saccharomyces cerevisiae (yeast)	Static magnetic field, 250 mT, 6 and 9 h	↑ lipid peroxidation and protein carboxylation			↑ SOD and CAT ↓GP_x after 9 h exposure		Decrease in growth after 6 h and an increase between between 6 and 9 h
Kunt et al. (2016)	47 electrical workers in power transmission facility, serum	Mean working period 15.9 ± 6.72 yrs						↑ oxidative stress index (increased total oxidant status, decreased antioxidant status)
Kurzeja et al. (2013)	Mouse fibroblast	Static MF, 0.4, 0.6, and 0.7 T, 4 days						Static MF reduced oxidative stress induced by fluoride ion by normalizing antioxidant enzymes.
Kuzay et al. (2017)	Healthy and diabetic male Wistar rats, testis tissue	50-Hz MF, 8.2 mT, 20 min/day. 5 days/week. 1 month	↑ lipid peroxidation	↑NO		↓GSH		
Lai and Singh (1998)	Sprague-Dawley rat in vivo, brain	60-Hz MF, 0.5 mT, 2 h	DNA strand breaks				DNA strand breaks blocked by melatonin and a spin-trap compound.	
Lai and Singh (2004)	Sprague-Dawley rat in vivo, brain	60-Hz MF, 0.01 mT, 24 or 48 h	DNA strand breaks				DNA strand breaks blocked by	Effects blocked by the iron

							Trolox and a nitric oxide synthase inhibitor.	chelator deferiprone
Lai et al. (2016)	Molt-4 human leukemia cells	0.2 Hz pulses, carrier modulated 134 KHz field from radiofrequency ID chip, 1 h					Effect blocked by the spin-trap compound N-tert-butyl-alpha-phenylnitrone	Cell death, effect also bloked by the iron-chelator deferoxamine
Lee et al. (2004)	Balb/c mouse in vivo, brain	60-Hz MF, 1.2 mT, 3 h	↑ lipid peroxidation	Ø $O_2^{\cdot-}$		↑SOD		
*Lee et al. (2012)	Mouse fibroblast NIH3T3	60-Hz MF, 1 mT, 4 h						MF did not affect H_2O_2-induced cellular transformation
Lee et al. (2010)	Human intervertebral disc cells	60-Hz EMF, 1.8 mT, 72 h						EMF induced DNA synthesis blocked by NMDA, a NO blocker
Lewicka et al. (2015)	Human blood platelet	EMF (1 kHz, 0.5 mT; 50 Hz, 10 mT, 1 kHz, 220 V/m), 30 min	↑ lipid peroxidation			↑ CAT		
*Li et al. (2015)	Human workers performed inspection near transformers and power lines, plasma	8-h time weighed average magnetic flux intensity 7.3 μT (1.56-26.33 μT), controls 0.07-0.72 μT	Ø lipid peroxidation			ØSOD Ø GPx		Ø Total antioxidant capacity, no change in micronucleus frequency
Li et al. (2013)	Male Drosophila melanogaster in vivo	50-Hz EMF, 72 h or long term (312 h), 3 mT						Short term exposure down-regulated CAT gene (endogenous antioxidant enzymes),

								trend of recovery with long term exposure
Lian et al. (2018)	Yeast (NT64C and SB34)	So Hz-M, 6 mT, 0.5- 24 h		↑ ROS at 0.5, 1 ad 2 h		↑ SOD at 1 h, ↑ CAT at 0.5 and 2 h		↑ generation and propagation of yeast prions; no ahnge in molecular chaperones (several heat-shock proteins)
Liu et al. (2014)	Sprague-Dawley rat cerebellum neurons	50-Hz MF, 1 mT, 1 h					Melatonin (MT) blocked MF-induced Na_v current, MT_2 receptor involved	
Liu et al. (2002)	Mouse in vivo, brain and liver	50-Hz EMF, 0.2 or 6 mT, 2 weeks	↑ lipid peroxidation, brain and liver			↓ GSH in liver		↓ decreased total antioxidant capacity in brain and liver, decreased cell membrane fluidity, synergism with lead
Luo et al. (2016)	ICR mouse Blood and cerebral cortex	50-Hz, 2-10 mT, 4 h/days. 28 days	↑ lipid peroxidation in serum and cerebral cortex			↓ SOD, ↓ CAT, ↓ glutathione reductase, ↓GSH-Px, and glutathione-s-transferase in serum and cerebral cortex		
Luo et al. (2019)	Sitobion avenae Fabricius (a herbivorous insect)	High-voltage electric field (HVEF); 2, 4. or 6 kV/cm; 20, 40, or 60 min; assayed up to 21 generations				↓ SOD, ↓ CAT, ↓peroxidase over multiple gererations		Exposed insects have higher Co2 production rate
Lupke et al. (2004)	Human umbilical cord blood derived	50-Hz MF, 1 mT, 45 min		↑ total ROS, ↑ $O_2^{\cdot-}$				Mono Mac 6 cells more sensitive,

	monocyte and human mono Mac 6 cells							activation of NADPH oxidase not NADH oxidase.
Luukkonen et al. (2014)	Human SH-SY5Y neuroblastoma cell	50-Hz MF, 0.1 mT, 24 h		↑ ROS, ↑ H_2O_2 in mitochondria				interacts with menadione; effects observed days after exposure
Malhmoudinasab et al. (2016)	Human MCF-7 cells	50-Hz EMF, 0.25 and 0.5 mT; 5-min on/5-min off; 15-min on/15-min-off, or 30 min continuously; total exposure time 30 min						Changes in mRNA levels of 7 antioxidant genes
Malhmoudinasab and Saadat (2018a)	Human SH-SY5Y and MCF-7 cells	50-Hz EMF, 0.5 mT, 15 min on/ 15 min off						Up-regulation of antioxidant genes and protection of Cisplatin cytotoxicity in SH-SY5Y cells, but not MCF-7 cells
Malhmoudinasab and Saadat (2018b)	Human SHSY5Y cells	50-Hz EMFm 0.5 mT, 15 min on/15 min off or 30 min continuously						Changes in antioxidant gene NQO1↓ and NQO2↑
Maliszewska et al. (2018)	American cockroach (Periplaneta Americana L)	50-Hz EMF, 7 mT, 24, or 72 h or 7 days	↑ lipid peroxidation			↓ GSH		
Manikonda et al. (2014)	Male Wistar rat in vivo, brain (hippocampus, cerebellum and cortex)	50-Hz MF, 0.05 and 0.1 mT, 90 days	↑ lipid peroxidation	↑ ROS		↑SOD ↓ GSH/GSSG ratio		Larger response at 0.1 mT
Mannerling et al. (2010)	Human leukemia cell K562	50-Hz MF, 0.025-0.1 mT, 1 h		↑ $O_2^{\cdot-}$			Melatonin blocked MF-	

							induced HSP70	
*Markkanen et al. (2010)	Murine L929 fibroblast	50-Hz MF, 0.1-0.3 mT, 1 h						Did not affect ROS production induced by UV.
Martinez et al. (2016)	Human neuroblastoma NB69 cells	50-Hz MF, 0.1 mT, 3-h on/3-h off for 24, 42, or 63 h, or continuously for 15-120 min					MF-induced MAPK-p38 and ERK1/2 activation blocked by NAC	
Martinez-Samano et al. (2010)	Male Wistar rat in vivo, plasma , liver, kidney and heart	60-Hz EMF, 2.4 mT, 2 h	Ø lipid peoxidation			↓ SOD in plasma of MF and restrained rats Ø CAT ↓ GSH in heart		Interacts with restraint stress
Martinez-Samano et al. (2012)	Male Wistar rat in vivo, brain	60-Hz EMF, 2.4 mT, 2 h				↓SOD ↓ CAT Ø GSH		Interacts with restraint stress
Martinez-Samano et al. (2018)	Male Wistar rat in vivo, brain	60-Hz EMF, 2.4 mT, 2 h/day, 21days	↑ lipid peroxidation in cortex and cerebellum					↑ plasma corticosterone
Martino (2011)	Human umbilical vein endothelial cell	Static MF, 0.12 and 0.03 mT (compared to 0.2-1 μT), 2 days					Increased cell proliferation attenuated by SOD	
Martino and Castello (2011)	Human fibrosarcoma HT1080, pancreatic AsPC-1 cancer cells, and bovine pulmonary artery endothelial cells	Static MF, geomagnetic field (45-60 μT) or shielded field (0.2-2 μT), 24 h		↓ H_2O_2 in shielded samples compared to geomagnetic field			MnTBAP (a ROS scavenger) inhibited MF effect.	

Medina-Fernandez et al. (2017)	Ale Dark Agouti rat; experimental model of multiple sclerosis induced by myelin oligodendrocyte glycoprotein (MOG), brain and spinal cord	Transcranial magnetic stimulation (TMS), 60-Hz, 0.7 mT, 2 h/day, 5 days a week, 3 weeks	TMS reversed protein carboxylation and lipid peroxidation induced by MOG			↑ GSH		Decreased cell death and motor deficit induced by MOG
Medina-Fernandez et al. (2018)	Ale Dark Agouti rat; experimental autoimmune encephalomyelitis induced by myelin oligodendrocyte glycoprotein (MOG), brain, spinal cord and blood	Transcranial magnetic stimulation (TMS), 60-Hz, 0.7 mT, 2 h/day, 5 days a week, 3 weeks	TMS reversed protein carboxylation and lipid peroxidation induced by MOG			↑ GSH		TMS reversed tail and limb paralysis induiced by MOG
Merle et al. (2019)	Human SH-SY5Y neuroblastoma cells	50-Hz MF, 1 mT, 24 h		↑ $O_2^{\cdot-}$ and H_2O_2				Effects involved NADPH-oxidase on plasma membrane

Miao et al. (2017)	Male BALB/c mice, in vivo, testicle	Electromagnetic pulse, 200 kV/m, pulse edge 25nsm pukse width 15 ns, 0.1 Hz, 40 pulses/day, 5 days/week, 4 weeks				↓ Testicular antioxidative capacity at 28 and 60 days after exposure		↓ spermatozoa formation
Miliša et al. (2017)	Euglena viridis and Paramecium caudatum	50-Hz EF, 2.5, 5.0, 9.3 and 13.6 kV/m, 24 h		↑ $O_2^{\cdot-}$ and H_2O_2,		↑SOD		
*Missiha et al. (2015)	Flavin-dependent redox enzymes	Static MF, 10-160 mT, seconds						MF did not change enzyme kinetics. Radical pair not a mechanism of redox reaction with static MF.
Mohammadi et al. (2018)	Tobacco cells	Static Magnetic field, 0.2 mT, 24 h		↑ H_2O_2, ↑ NO				Delayed G1-S transition, increased cyclic nucleotides
Morabito et al. (2010a)	Rat pheochromocytoma PC-12 cell	50-Hz MF. 0.1 or 1 mT, 30 min or 7 days		↑ ROS in 30 min exposure at 1 mT.		↓ CAT in 0.1 and 1 mT 30-min exposure, ↑ catalase in 1 mT 7-day exposure		All effects were observed in undifferentiated and not in differentiated cells. Calcium probably involved.
Morabito et al. (2010b)	Undifferentiated C2C12 myoblast	50-Hz MF. 0.1 or 1 mT, 30 min		Ø $O_2^{\cdot-}$ ↑ H_2O_2 in 1 mT exposure		↑ CAT and GPx	NAC attenuated free radical increase by MF	Calcium probably involved.
Naarala et al. (2017)	Rat glioma C6 cells	Nearly vertical 33 μT static MF plus a horizontal or a		↑ cytosolic $O_2^{\cdot-}$ in vertical static field plus horizontal 50-Hz MF (but not vertical 50-				Cell viability not affected.

		vertical 50-Hz 30 μT MF, 2 h		Hz MF); Mtochondrial $O_2^{\cdot-}$ not affected				
*Nakaya ma et al. (2016)	Mouse macrophage (RAW 264) with or without LPS stimulation	50-Hz MF, 0.5 mT, 24 h		Ø NO				
Noda et al. (2000)	Rat brain cerebellum tissues	Pulsed DC MF, 0.1 mT, 1 h			↑NOS			No effect from pulsed DC at 0.3 and 0.6 mT, 60 Hz (0.1 mT), and DC (3 or 20 mT) MF, no effect in hippocampus, cortex, medulla oblongagta, hypothalamus, striatum, and midbrain.
Osera et al. (2011)	Human neuroblastoma SH-SY5Y cells	72-Hz pulsed EMF, 1.3 ms pulse duration, 2 mT, 72 h				↑SOD-1		Increased quiescent cells
Osera et al. (2015)	Human neuroblastoma SH-SY5Y cells	72-Hz pulsed EMF, 1.3 ms pulse duration, 2 mT, 10, 15, or 30 min for 4 times over 7 days, or 72 h				↑Mn-SOD		Interacts with H_2O_2. Pulsed EMF prevented H_2O_2 – induced decrease in cell number and protein expression (HSP70).
Pakhomova et al. (2012)	Jurket cells	Nanosecond pulsed electric field (300 ns, 1-12 kV/cm)		↑ROS proportional to pulse number				No effect on U937 cells
Pandir and Sahingoz (2014)	Moth Ephesta kuehniella larvae	Static MF, 1.4 T; 3, 6, 12, 24, 48, or 72 h	↑ lipid peroxidation			Exposure-time dependent ↓ SOD, CAT, GPx and GST		

Park et al. (2013)	Human bone marrow mesenchymal stem cells	50-Hz EMF, 1 mT, 90 min		↑ROS			Blocked by NAC	
Patruno et al. (2010)	Human epidermal keratinocyte cell HaCaT	50-Hz MF, 1 mT, 3, 18, 48 h		↓ $O_2^{\cdot-}$ ↑NO	↑iNOS and eNOS	↓ CAT		Increased cell proliferation.
Patruno et al. (2011)	Human epidermal keratinocyte cell HaCaT and acute myeloid leukemia THP-1 cell	50-Hz MF, 1 mT, 24 h			↑iNOS activity	↑ CAT activity		
Patruno et al. (2012)	Human acute myeloid leukemia THP-1 cell	50-Hz MF, 1 mT, 24 h		↑ $O_2^{\cdot-}$	↑iNOS	↓SOD ↓ CAT		
Patruno et al. (2015)	Human erythro-leukemic K562 cell	50-Hz MF, 1 mT, 24 h			↓ iNOS reaction velocity	↑ CAT activity		
Pilla (2012)	Human dopaminergic MN9D cells and fibroblasts	Pulsed radiofrequency signal, 2 Hz, with 127.2 MHz carrier; 2.5 μT, 15 min		↑NO				May involve activation of calcium/calmodulin nitric oxide synthase (cNOS)
Politanski et al. (2010)	C57BL/g mouse in vivo, cochlear	Static MF, 5 mT, 2 h, repeated over 14 days (also exposed to noise once)	↑ lipid peroxidation in 'MF + noise'			↑ SOD in MF, noise, and 'MF + noise', ↑ CAT activity in MF, noise, and 'MF + noise'		MF interacted with noise
Poniedzialek et al. (2013a)	Human neutrophil	EMF tuned to calcium ion cyclotron resonance frequency (up to 60 μT)		↓ ROS in unstimulated cells, ↑ in phorbol 12-myristate 13-acetate stimulated cells				
Poniedzialek et al. (2013b)	Human neutrophil	Gradient static MF, maximum value 60 mT, 15, 30 or 45 min		↓ ROS in 15-min exposure, ↑ in 45-min exposure in both unstimulated and phorbol 12-myristate 13-acetate stimulated cells, effect				

				depended on whether samples were placed close to south or north pole of magnet.				
Pooam et al. (2017)	Human macrophage RAW264	50 Hz MF, 0.1 or 0.5 mT, 1, 17 or 24 h		↑ $O_2^{\cdot-}$				
Potenza et al. (2010)	Human umbilical vein endothelial cells	Static MF, 300 mT, 4, 24, 48,and 72 h		↑ROS only at 4-h exposure coincided with DNA damage				
Rageh et al. (2012)	10 -day old rat in vivo, brain	50-Hz MF. 0.5 mT, 30 days (24 h/day)	↑ lipid peroxidation			↑ SOD Ø GSH		
Raggi et al. (2008)	Human blood sample	Magnetic therapy device based on ion cyclotron resonance	↓ lipid peroxidation immediately and one month after exposure					
Rajabbeigi et al. (2013)	Parsley cell	Static MF, 30 mT, 6 or 12 h				↑ CAT with MF ↓ CAT with 'MF + iron'		↓ ascorbate peroxidase
Rauš Balind et al. (2014)	Gerbil subjected to 10-min global cerebral Ischemia in vivo, brain(forebrain, striatum and hippocampus)	50-Hz MF, 0.5 mT, 7 days						MF decreased oxidative stress induced by ischemia (NO, SOD, MDA, $O_2^{\cdot-}$)
Reale et al. (2006)	Human blood monocytes	50-Hz EMF, 1 mT, overnight			↓ iNOS			
Reale et al. (2014)	Human neuroblastoma cell SH-SY5Y	50-Hz MF, 1 mT, 1, 3, 6 or 24 h		↑ $O_2^{\cdot-}$	↑ NOS, peaked at 1 h	↑ CAT		MF enhanced oxidative effects of H_2O_2 (↓catalase, ↑ $O_2^{\cdot-}$).
Regoli et al. (2005)	Snail Helix aspersa in vivo,	50-Hz MF, 0.5, 2.5,10 and 50 μT, 10 days in lab;	Lab: Ø lipid peroxidation Field: ↑ in 2.88 μT more than 10 days and 0.75 μT more than 20 days			Lab:↓ CAT in 50 μT 10 days Field: ↓ CAT in 2.88 μT more than 10 days and 0.75 μT more than 40 days		Total oxyl-radical scavenger capacity:

	digestive gland	2.88 and 0.75 μT for 10, 20, 40, 60 days in field				Lab: Ø GSH, ↓ Glutathione reductase Field: ↓ glutathione reductase		Lab: ↓OH and ROO; Field: ↑OH and ↓ROO
Rollwitz et al. (2004)	Mouse bone marrow-derived promonocytes and macrophage	50-Hz MF, 1 mT, 45 min-24 h		↑ ROS, ↑ $O_2^{\cdot-}$				NADH-oxidase (not NADPH pathway) involved.
*Romeo et al. (2016)	Human fetal lung fibroblasts (MRC-5)	Static MFm 370 mT, 1 h/day for 4 days		Ø ROS				Ø viability, DNA strand breaks, and apoptosis
Roy et al. (1995)	Phorbol 12-myristate 13-acetate-stimulated rat neutrophil	60-Hz MF, 0.1 mT		↑ ROS				
Sadeghipour et al. (2012)	Human breast carcinoma cell (T47D)	100 and 217 Hz pulsed EMF, 0.1 mT, 24-72 h		↑ ROS in 217 Hz 72-h, not in 100 Hz exposure				
Sahebjamei et al. (2007)	Cultured tobacco cell	Static MF, 10 and 30 mT, 5 h/day, 5 days	↑ lipid peroxidation			↑SOD ↓ CAT and ascorbate peroxidase		
Salunke et al. (2014)	Swiss albino mouse in vivo, brain	50-Hz MF, 1 mT, 8 h/day for 7, 30, 60, 90 and 120 days		↑ NO in cortex, hippocampus, and hypothalamus				
Seif et al. (2018)	Male Wistar rats, in vivo blood	So-Hz EMF, 0.7 mT, 2 h/day. 1 month	↑ plasma protein carboxylation, methemoglobin and hemichrome			↓ plasma anti-oxidation capacity		
Seifirad et al. (2014)	Male Wistar rat in vivo, serum	60-Hz MF, 0.5 mT, 4 h or 4 h/day 14 days	↑lipid peroxidation immediately after and at 72 h after chronic exposure, Ø acute exposure					Total antioxidant activity: ↑ immediately after acute exposure (not at 3 days post-exposure), ↓immediately and 3 days

								after chronic exposure.
Selaković et al. (2013)	Male gerbils 3- and 10-month old in vivo, Forebrain cortex, striatum hippocampus, and cerebellum	50-Hz MF, 0.5, 0.25 and 0.1 mT, 7 days	↑ lipid peroxidation	↑ $O_2^{\cdot-}$ ↑NO		↑SOD		Dose-response observed, effects smaller and recovered faster in 3-month than in 10-month old animals.
Sharifian et al. (2009)	Human welders occupational exposure, serum and red blood cells	50-Hz EMF, 8.8-84 μT, 20-133 V/m, 40 h/week (6 days/ week)				↓SOD ↓GPX		Ø Total serum antioxidant status, a significant negative correlation between SOD/GPX and MF intensity was observed.
Sherrard et al. (2018)	Insect sf21 cells, human embroyonic kidney cells, mouse embryonic fibroblasts	Pulsed EMF. 10 Hz, peak intensity 2 mT, 15 min; with blue light		↑ROS				Effects involved cryptochromes
Shine et al (2012)	Soybean seeds	Static MF 150 and 200 mT, 1 h		↑ $O_2^{\cdot-}$, OH, H_2O_2,		↓SOD & ascorbate peroxidase		
Shokrolahi et al. (2018)	Soybean plants	Static MF, 20 and 30 mT, 5 days, 5 h/day		At 20 mT, ↓ H_2O_2,; at 30 mT, ↑ H_2O_2,		At 20 mT, ↓ CAT,, at 30 mT, ↑ CAT,		At 20 mT, ↓ gene expression of Fe transporter, ferrous content,, and gene expression and content of ferritin;,, 30 mT produced

								the opposite effects of these parameters
Simko et al. (2001)	Mouse bone marrow-derived macrophage	50-Hz MF, 0.5-1.5 mT, 45 min		↑ $O_2^{\cdot-}$				Increased phagocytic activity.
Sirmatel et al. (2007a)	Male human blood	1,5 T static MF from a MRI machne, 30 min						↑ total antioxidant capacity; ↓ total oxidant ststus and oxidative stress index
Sirmatel et al. (2007b)	Male human blood	1,5 T static MF from a MRI machne, 30 min		↑ NO (based on nitrite and nitrate leveks)				
Solek et al. (2017)	Mouse spermatogenic cell lines	2, 50, 120 Hz pulsed (1 sec on/1 sec off) and continuous-wave EMF, 2.5-8 mT, 2 h		↑ $O_2^{\cdot-}$ ↑ NO				Cell cycle arrest and apoptosis observed
Song et al. (2018)	Human cerical cancer cells (HeLa) and lung fibroblasts (IMR-90)	60-Hz EMF 1-10 mT, up to 72 h		↓ROS				Increased cell proliferation
Sullivan et al. (2011)	Various human cell lines	Static MF, 35-120 mT		Static MF ↑ ROS at 18 h (not at 5 days) of exposure in fetal lung (WI38) cells.				Effects observed in some cell types and not in others.
Sun et al. (2015)	Preosteoclast cell line RAW264.7	Large gradient high magnetic fields (12 T, -1370 T^2/m; 12 T, 1370 T^2/m), 48 h		↓ NO				
Sun L.et al. (2018)	Human amnion epithelial cells	50-Hz MF, 0.4 mT, 15 min		↑ ROS			Inhibited by N-accetyl-l-cysteine and pyrrolidine	Increase in free radicals correlated to clustering of

							dithiocarbamate	cell surface epidermal growth factor receptor
Sun Y. et al. (2018)	Caenorhabditis elegans	50-Hz EMF, 3 mT. exposed from egg to fouth larva stage		↑ ROS				
Tang et al. (2016)	Human Jurket cell and stimulated mouse primary T cell	7.5 Hz MF, 0.4 T, 2 h		↑ ROS		↑Total anti-oxidant activity, Ø SOD, Ø CAT		Disruption of tricarboxylic acid cycle enzymes PGE2 and formation
Tasset et al. (2012)	Male Wistar rat in vivo, brain	60-Hz MF, 0.7 mT, 2 h in the morning and 2 h in the afternoon for 21 days (applied to the head)	Ø DNA oxidative damage Ø lipid peroxidation			Ø GSH ↓ GSSG		MF reversed 3-nitropropionic acid induced oxidative stress.
Tayefi et al. (2010)	Wistar rat pup in vivo, myocardium	50-Hz MF, 3 mT, 4/h per day during gestation and to 20 day postnatal	↑ lipid peroxidation			↓ SOD		
Todorovic et al. (2012)	Eggs of Baculum extradentatum (insert also known as Vietnamese walking stick)	Stattic MF, 50 mT; 50-Hz MF, 6 mT; exposed until completion og embryonic development				↑SOD and CAT Ø GSH		
Todorovic et al. (2019)	One-month old Blaptica dubia (cockroach) nymphs; gut assayed	110 mT Static MF or 10 mT 50-Hz MF, for 5 months				↑ SOD and CAT; Ø GSH; ↓GST and glutathione reductase		MF exposure decreased gut mass of developing cockcoach
Túnez et al. (2006)	Male Wistar rat in vivo, striatum	60-Hz MF, 0.7 mT, 2 h in the morning and 2						MF itself had no effect on different

		h in the afternoon for 4 days (applied to the head)						oxidative parameters, but reduced 3-nitropropionic acid induced oxidative and nitrosative stress.
*Türközer et al. (2008)	Guinea pig in vivo, brain	50-Hz EF, 2, 2.5, 3, 3.5, 4, 4.5, 5 V/m, 8 h/day, 3 days	Ø lipid peroxidation			Ø SOD Ø CAT and GPx		
Van Huizen et al. (2019)	Schmidtea mediterranea (planarian), regeneration after amputation	Static magnetic field;100-400 μT and 500 μT; 12, 24 or 48 h		↓ ROS after 100-400 μT and ↑ ROS after 500 μT exposure				Reduced blastema (regrowth) size at 100-400 μT, increased at 500 μT; ROS altered stem cell proliferation and differentiation depending on field intensity, inhibiting SOD pharmacologically reversed decreased regeneration effect of 200 μT
*Vannoni et al. (2012)	Human osteoarthritic chondrocyte	100-Hz EMF and a field containing various frequencies		Ø ROS		Ø GSH		
Vignola et al. (2012)	Female Wistar rat with drug-induced myopathy, in vivo, muscle	Pulsed EMF, 50-Hz carrier frequency, 20 mT, 30 min/day, 8 days, assayed		↓NO		↓SOD		Pulsed EMF caused muscle recovery.

		8 days after exposure						
*Villarini et al. (2017)	SH-SY5Y5 and SK-N-BE-2 human neuroblastoma cells	50-Hz MF; 0.01, 0.1, or 1 mT; 1 h continuously or 5 h intermittently	Ø DNA damage			Ø GSH/GSSG ratio		
Wang et al. (2019)	11 cancer and normal cell lines	Static magnetic field and 50- and 120-Hz MF, 6 mT,, 2, 4, or 6 h		ROS measured in 4 cell lines after 2 h exposure. ↑ and ↓ ROS observed depeding on cell line and field				No change in ATP levels, ↑ and ↓ in mitochondrial membrane potential depending on cell type
Wartenberg et al. (2008)	Oral mucosa cancer cell (UM-SCC-14-C)	DC EF, 4 V/m, 24 h				↑ Cu/Zn SOD Ø CAT ↓GSH	Effects blocked by NAC.	Increased apoptosis and decreased cell proliferation.
Wolf et al. (2005)	HL-60 leukemia cells, Rat-1 fibroblast, WI-38 diploid fibroblast	50-Hz EMF, 0.5-1 mT, 24-72 h	↑ DNA oxidative damage	↑ ROS in Rat-1 fibroblast			Effect blocked by alpha-tocopherol.	Dose-dependent increase in cell proliferation observed.
Wu et al. (2016)	Male mice, liver	Static E-field, 9.2-21.85 kV/m, 2.3-15.4 kV/m, and 0 kV/m, 35 days	Ø lipid peroxidation			↑ SOD		No effect on glutathione-transferase and glutathione peroxidase
Yang and Ye (2015)	Human osteosarcoma MG-63 cells	50-Hz EMF; 1 mT; 1,2 or 3 h		↑ ROS			Blocked by N-acetylcysteine	↓ viability and cell growth; ↑ apoptosis
Yang et al. (2016)	Sprague-Dawley rats and isolated microglial cells	EMP, 200 kV/m, 200 pulses; assayed at 1, 6, 12 and 24 h after exposure		↑ NO in cerebral cortex of rats and microglial cells, effect returned to normal at 24 h				
Yin et al. (2016)	Primary cultured rat	50-Hz MF, 8 mT, 90 min	↑ lipid peroxidation	↑ ROS		↓SOD		

	hippocampal neurons							
Yokus et al. (2005)	Female Wistar rat in vivo, leukocytes and plasma	50-Hz MF, 0.97 mT, 3 h/day for 50 or 100 days	↑ DNA oxidative damage ↑lipid peroxidation					Larger effects with longer exposure.
Yokus et al. (2008)	Male Sprague-Dawley rat in vivo, leukocytes	50-Hz MF, 0.1 and 0.5 mT, 2 h/day for 10 months	↑ different forms of oxidative DNA damage in 0.1 mT group					
*Yoon et al. (2014)	Human lung fibroblast W138 and human lung epithelial L132 cells	60-Hz MF, 1 or 2 mT, 6 h						MF did not enhance H_2O_2-induced double strand DNA breaks.(MF potentiated infra-red induced breaks).
*Yoshikawa et al. (2000)	Male BALB/C mouse injected with lipopolysaccharide (LPS) in vivo, liver	60-Hz MF, 0.1 mT, 5.5 h						MF did not induce NO generation, but enhanced LPS-induced NO generation.
Zeng et al. (2011)	Male Sprague-Dawley rats	EMP, 100 kV/m, 50 pps 2.5-2.8 ns width, total pulses 4x 10^5	↑ lipid peroxidation in testes			↓total SOD and manganese-SOD in testes		Changes in ultrastructures of testes
Zeng et al. (2017)	Hippocampal neurons from embryonic Sprague-Dawley rats	50-Hz MF, 2 mT; acute; 30 min, 8 h or 24 h on DIV (days in vitro) 7or 14; repeated: 30 min or 8 h DIV1-7 or DIV 7-14		↑ ROS after repeated exposure				↓ cell viability; ↑ expression of NADPH oxidase (subunit Nox2), respobsible for ROS production
Zhang et al. (2016)	Canton Special and W1118 flies	50-Hz MFn 30 mT, 12 h						Acted synergistically with heat

								on oxidative stress and induction of heat shock proteins, effects depends on species and sex
Zhang et al. (2017)	Workers occupationally exposed to EMFin a power plant	>20 yrs	↑ DNA oxidative damage (8-OHdG measured in plasma)				Effects reversed by resveratrol (500 mg twice daily, 12 months)	Exposed subjects showed reduced inflammatory biomarkers
Zhang et al. (2018)	RAW 264.7 bone monocytes	Static MF, 500 nT, 0.2 T, 16 T; 12 h to 4 days		↑ NO (16 T) ↓ NO (500 nT and 0.2 T)	↑ NOS (16 T) ↓ NOS (500 nT and 0.2 T)			NO mediates SMF effects on osteoclast formation; effect depends on intensity of MF
Zhao et al. (2011)	Human-hamster hybrid(A9L)), mitochondria-deficient (p(0)A(L)) cells, double-strand break repair-deficient (XRS-5) cells	Static MF, 8.5 T, 3 h		↑ ROS				
Zwirska-Korczala et al. (2004)	Murine squamous carcinoma AT478 cell	Mixture of frequencies up to 400 Hz, MF, 0.11 mT, 16 min, assayed 24 and 72 h after exposure	↑lipid peroxidation			↑ MnSOD and Cu/ZnSOD Ø GPx	Effects attenuated by melatonin	

Zmylony et al. (2004a)	Rat lymphocytes stimulate by $FeCl_2$	50-HZ MF, 20, 40, or 200 μT, 5 or 60 min		↓ ROS in Fe and 40 μT MF exposed cells (AC MF has to be directed along the earth's static MF).				
Zmylony et al. (2004b)	Rat lymphocytes	50-HZ MF, 40 μT, 5 or 60 min	MF enhanced DNA damage caused by ultraviolet radiation (UVA). (UVA damages DNA via free radicals.)					

Literature list (E= 212 (89%); NE= 27 (11%)) (E= paper reported effect; NE= paper reported no significant effect).

(VT = in vitro; VO= in vivo; HU= human study; CE = long-term/repeated exposure; AE= acute exposure; LI = low intensity; IFR= increase free radical; DFR= decrease free radical; IOD = increase oxidative damages; DOD = decrease oxidative damages; IAO =increase antioxidant activity; DAO= decrease antioxidant activity; AO= effect of antioxidant/free radical scavenger; IX= interaction with other factor; MC= mechanism)

(E) (VT, AE, IFR, IAO) Akan Z, Aksu B, Tulunay A, Bilsel S, Inhan-Garip A. Extremely low-frequency electromagnetic fields affect the immune response of monocyte-derived macrophages to pathogens. Bioelectromagnetics. 31(8):603-612, 2010.

(E) (VO, CE, DFR) Akdag MZ, Bilgin MH, Dasdag S, Tumer C. Alteration of nitric oxide production in rats exposed to a prolonged, extremely low-frequency magnetic field. Electromagn Biol Med. 26(2):99-106, 2007.

(E) (VO, CE, DAO) Akdag MZ, Dasdag S, Ulukaya E, Uzunlar AK, Kurt MA, Taşkın A. Effects of extremely low-frequency magnetic field on caspase activities and oxidative stress values in rat brain. Biol Trace Elem Res. 138(1):238-249, 2010.

(E) (VO, CE, IOD) Akdag MZ, Dasdag S, Cakir DU, Yokus B, Kizil G, Kizil M. Do 100- and 500-μT ELF magnetic fields alter beta-amyloid protein, protein carbonyl and malondialdehyde in rat brains? Electromagn Biol Med. 32(3):363-372, 2013a.

(NE) (VO, CE) Akdag MZ, Dasdag S, Uzunlar AK, Ulukaya E, Oral AY, Celik N, Akşen F. Can safe and long-term exposure to extremely low frequency (50 Hz) magnetic fields affect apoptosis, reproduction, and oxidative stress? Int J Radiat Biol. 89(12):1053-1060, 2013b.

(E) (VO, CE, IOD) Akpinar D, Ozturk N, Ozen S, Agar A, Yargicoglu P. The effect of different strengths of extremely low-frequency electric fields on antioxidant status, lipid peroxidation, and visual evoked potentials. Electromagn Biol Med. 31(4):436-448, 2012.

(E) (VO, CE, DOD, IOD) Akpınar D, Gok DK, Hidisoglu E, Aslan M, Ozen S, Agar A, Yargicoglu P. Effects of pre- and postnatal exposure to extremely low-frequency electric fields on mismatch negativity component of the auditory event-related potentials: Relation to oxidative stress. Electromagn Biol Med. 35(3):245-259, 2016.

(E)(VO, CE, IOD) Aksen F, Akdag MZ, Ketani A, Yokus B, Kaya A, Dasdag S. Effect of 50-Hz 1-mT magnetic field on the uterus and ovaries of rats (electron microscopy evaluation). Med Sci Monit. 12(6):BR215-220, 2006.

(NE) (VO, CE, AO) Alcaraz M, Olmos E, Alcaraz-Saura M, Achel DG, Castillo J. Effect of long-term 50 Hz magnetic field exposure on the micronucleated polychromatic erythrocytes of mice. Electromagn Biol Med. 33(1):51-57, 2014.

(E) (VO, CE, DAO, IOD) Amara S, Douki T, Garel C, Favier A, Sakly M, Rhouma KB, Abdelmelek H. Effects of static magnetic field exposure on antioxidative enzymes activity and DNA in rat brain. Gen Physiol Biophys. 28(3):260-265, 2009.

(E) (VO, CE, DAO, IOD, IX) Amara S, Douki T, Garrel C, Favier A, Ben Rhouma K, Sakly M, Abdelmelek H. Effects of static magnetic field and cadmium on oxidative stress and DNA damage in rat cortex brain and hippocampus. Toxicol Ind Health. 27(2):99-106, 2011.

(E) (VO, AE, CE, IAO) Ansari AM, Farzampour S, Sadr A, Shekarchi B, Majidzadeh-A K. Effects of short term and long term extremely low frequency magnetic field on depressive disorder in mice: Involvement of nitric oxide pathway. Life Sci. 146:52-57, 2016.

(E) (VO, AE, IAO) Asghar T, Jamil Y, Iqbal M, Zia-Ul-Haq, Abbas M. Laser light and magnetic field stimulation effect on biochemical, enzymes activities and chlorophyll contents in soybean seeds and seedlings during early growth stages. J Photochem Photobiol B. 165:283-290, 2016.

(E) (VT, CE, IFR) Ayşe IG, Zafer A, Sule O, Işil IT, Kalkan T. Differentiation of K562 cells under ELF-EMF applied at different time courses. Electromagn Biol Med. 29(3):122-130, 2010.

Barnes F, Greenebaum B. Role of radical pairs and feedback in weak radio frequency field effects on biological systems. Environ Res. 163:165-170, 2018. (Review)

(E) (VT, AC, IX) Bawin SM, Satmary WM, Jones RA, Adey WR, Zimmerman G. Extremely-low-frequency magnetic fields disrupt rhythmic slow activity in rat hippocampal slices. Bioelectromagnetics. 17(5):388-395, 1996.

(E) (VO, CE, IOD) Bediz CS, Baltaci AK, Mogulkoc R, Oztekin E. Zinc supplementation ameliorates electromagnetic field-induced lipid peroxidation in the rat brain. Tohoku J Exp Med. 208(2):133-140, 2006.

(E) (VT, AE, IFR, DFR, MC) Belova NA, Potselueva MM, Skrebnitskaia LK, Znobishcheva AV, Lednev VV. The influence of weak magnetic fields on the production of the reactive oxygen species in peritoneal neutrophils in mice. Biophysics (Biofizika). 55(4):586-591, 2010.

(E) (VT, AE, IOD, IX) Benassi B, Filomeni G, Montagna C, Merla C, Lopresto V, Pinto R, Marino C, Consales C. Extremely low frequency magnetic field (ELF-MF) exposure sensitizes SH-SY5Y cells to the pro-Parkinson's Disease toxin MPP. Mol Neurobiol. 53(6):4247-4260, 2016.

Brocklehurst B, McLauchlan KA. Free radical mechanism for the effects of environmental electromagnetic fields on biological systems. Int J Radiat Biol. 69(1):3-24, 1996. (Review)

(E) (VT, AE, IOD) Buczyński A, Pacholski K, Dziedziczak-Buczyńska M, Henrykowska G, Jerominko A. The assessment of oxygen metabolism selected parameters of blood platelets exposed to low frequency magnetic radiation in cars--in vitro studies. Rocz Akad Med Bialymst. 50 Suppl 1:23-25, 2005.

(E) (VO, CE, LI, DAO, IAO) Budziosz J, Stanek A, Sieroń A, Witkoś J, Cholewka A, Sieroń K. Effects of low-frequency electromagnetic field on oxidative stress in selected structures of the central nervous system. Oxid Med Cell Longev. 2018:1427412, 2018.

(E) (VT, AE, DOD, IAO, IX) Bułdak RJ, Polaniak R, Bułdak L, Zwirska-Korczala K, Skonieczna M, Monsiol A, Kukla M, Duława-Bułdak A, Birkner E. Short-term exposure to 50 Hz ELF-EMF alters the cisplatin-induced oxidative response in AT478 murine squamous cell carcinoma cells. Bioelectromagnetics. 33(8):641-651, 2012.

(E)(VT, AE, IFR) Calabrò E, Condello S, Currò M, Ferlazzo N, Caccamo D, Magazù S, Ientile R. Effects of low intensity static magnetic field on FTIR spectra and ROS production in SH-SY5Y neuronal-like cells. Bioelectromagnetics. 34(8):618-629, 2013.

(E) (VT, AE, IFR, IOD, DAO) Calcabrini C, Mancini U, De Bellis R, Diaz AR, Martinelli M, Cucchiarini L, Sestili P, Stocchi V, Potenza L. Effect of extremely low-frequency electromagnetic fields on antioxidant activity in the human keratinocyte cell line NCTC 2544. Biotechnol Appl Biochem. 64(3):415-422, 2017.

(E) (VT, AE, DFR) Calota V, Dragoiu S, Meghea A, Giurginca M. Decrease of luminol chemiluminescence upon exposure of human blood serum to 50 Hz electric fields. Bioelectrochemistry. 69(1):126-127, 2006.

(E)(VT, AE, IFR) Calota V, Dragoiu S, Meghea A, Giurginca M. Effects of prooxidants on human serum exposed to 50 Hz magnetic fields. Electromagn Biol Med.26(2):135-140, 2007.

(E)(VO, CE, DOD, IOD, DFR, IFR) Canseven AG, Coskun S, Seyhan N. Effects of various extremely low frequency magnetic fields on the free radical processes, natural antioxidant system and respiratory burst system activities in the heart and liver tissues. Indian J Biochem Biophys. 45(5):326-331, 2008.

(E) (VT, AE, IFR) Chen Y, Hong L, Zeng Y, Shen Y, Zeng Q. Power frequency magnetic fields induced reactive oxygen species-related autophagy in mouse embryonic fibroblasts. Int J Biochem Cell Biol. 57:108-114, 2014.

(E)(VT, AE, IX) Cheun BS, Yi SH, Baik KY, Lim JK, Yoo JS, Shin HW, Soh KS. Biophoton emission of MDCK cell with hydrogen peroxide and 60 Hz AC magnetic field. J Environ Biol. 28(4):735-740, 2007.

(E) (VT, AE, IFR, IOD, IAO) Chu LY, Lee JH, Nam YS, Lee YJ, Park WH, Lee BC, Kim D, Chung YH, Jeong JH. Extremely low frequency magnetic field induces oxidative stress in mouse cerebellum. Gen Physiol Biophys. 30(4):415-421, 2011.

(E) (VO, AE, IFR) Chung YH, Lee YJ, Lee HS, Chung SJ, Lim CH, Oh KW, Sohn UD, Park ES, Jeong JH. Extremely low frequency magnetic field modulates the level of neurotransmitters. Korean J Physiol Pharmacol. 19(1):15-20, 2015.

(E) (VO, HU, CE, IAO) Cichoń N, Bijak M, Miller E, Saluk J. Extremely low frequency electromagnetic field (ELF-EMF) reduces oxidative stress and improves functional and psychological status in ischemic stroke patients. Bioelectromagnetics. 38(5):386-396, 2017a.

(E) (HU, CE, IFR) Cichoń N, Czarny P, Bijak M, Miller E, Śliwiński T, Szemraj J, Saluk-Bijak J. Benign effect of extremely low-frequency electromagnetic field on brain plasticity assessed by nitric oxide metabolism during poststroke rehabilitation. Oxid Med Cell Longev. 2017:2181942, 2017b.

(E) (HU, CE, IAO) Cichon N, Bijak M, Synowiec E, Miller E, Sliwinski T, Saluk-Bijak J. Modulation of antioxidant enzyme gene expression by extremely low frequency electromagnetic field in post-stroke patients. Scand J Clin Lab Invest. 78(7-8):626-631, 2018a.

(E) (HU, CE, DOD) Cichoń N, Rzeźnicka P, Bijak M, Miller E , Miller S, Saluk J. Extremely low frequency electromagnetic field reduces oxidative stress during the rehabilitation of post-acute stroke patients. Adv Clin Exp Med. 27(9):1285-1293, 2018b.

(E) (VO, CE, IAO, DAO) Ciejka EB, Goraca A. The influence of low-frequency magnetic field on plasma antioxidant capacity and heart rate. Wiad Lek. 62(2):81-86, 2009.

(E) (VO, CE, IFR) Ciejka E, Skibska B, Kleniewska P, Goraca A. [Influence of low frequency magnetic field on chosen parameters of oxidative stress in rat's muscles]. Pol Merkur Lekarski. 29(174):361-364, 2010. [Article in Polish]

(E) (VO, CE, IOD) Ciejka E, Kleniewska P, Skibska B, Goraca A. Effects of extremely low frequency magnetic field on oxidative balance in brain of rats. J Physiol Pharmacol. 62(6):657-661, 2011.

(E) (VO, CE, IAO) Ciejka E, Jakubowska E, Zelechowska P, Huk-Kolega H, Kowalczyk A, Goraca A. [Effect of extremely low frequency magnetic field on glutathione in rat muscles]. Med Pr. 65(3):343-349, 2014. [Article in Polish]

(E) (VO, CE, DFR, DOD, IAO, IX) Coballase-Urrutia E, Navarro L, Ortiz JL, Verdugo-Díaz L, Gallardo JM, Hernández ME, Estrada-Rojo F. Static magnetic fields modulate the response of different oxidative stress markers in a restraint stress model animal. Biomed Res Int. 2018:3960408, 2018.

Consales C, Merla C, Marino C, Benassi B. Electromagnetic fields, oxidative stress, and neurodegeneration. Int J Cell Biol. 2012:683897, 2012. (Review)

(E) (VT, AE, IFR) Consales C, Cirotti C, Filomeni G, Panatta M, Butera A, Merla C, Lopresto V, Pinto R, Marino C, Benassi B. Fifty-hertz magnetic field affects the epigenetic modulation of the miR-34b/c in neuronal cells. Mol Neurobiol. 55(7):5698-5718, 2018.

(NE) (IV, AE) Consales C, Panatta M, Butera A, Filomeni G, Merla C, Carrì MT, Marino C, Benassi B. 50-Hz magnetic field impairs the expression of iron-related genes in the in vitro $SOD1^{G93A}$ model of amyotrophic lateral sclerosis. Int J Radiat Biol. 95:368-377, 2019.

(E) (VO, CE, IFR, IOD) Coşkun S, Balabanli B, Canseven A, Seyhan N. Effects of continuous and intermittent magnetic fields on oxidative parameters in vivo. Neurochem Res. 34(2):238-243, 2009.

(E) (VO, CE, IOD, DAO) Cui Y, Ge Z, Rizak JD, Zhai C, Zhou Z, Gong S, Che Y. Deficits in water maze performance and oxidative stress in the hippocampus and striatum induced by extremely low frequency magnetic field exposure. PLoS One. 7(5):e32196, 2012.

(NE) (VT, AE) de Groot MW, Kock MD, Westerink RH. Assessment of the neurotoxic potential of exposure to 50 Hz extremely low frequency electromagnetic fields (ELF-EMF) in naïve and chemically-stressed PC12 cells. Neurotoxicology. 44:358-364, 2014.

(NE) (VT, AE, IX) De Mattei M, Pasello M, Pellati A, Stabellini G, Massari L, Gemmati D, Caruso A. Effects of electromagnetic fields on proteoglycan metabolism of bovine articular cartilage explants. Connect Tissue Res. 44(3-4):154-159, 2003.

(E)(VT, AE, IFR, IAO) De Nicola M, Cordisco S, Cerella C, Albertini MC, D'Alessio M, Accorsi A, Bergamaschi A, Magrini A, Ghibelli L. Magnetic fields protect from apoptosis via redox alteration. Ann N Y Acad Sci. 1090:59-68, 2006.

(E) (VT, VO, AE, IOD, DAO, IX) Deng B, Xu H, Zhang J, Wang J, Han LC, Li LY, Wu GL, Hou YN, Guo GZ, Wang Q, Sang HF, Xu LX. Neuroprotective effects of sevoflurane against electromagnetic pulse-induced brain injury through inhibition of neuronal oxidative stress and apoptosis. PLoS One. 9(3):e91019, 2014.

(E) (VO, CE, IOD, DAO) Deng Y, Zhang Y, Jia S, Liu J, Liu Y, Xu W, Liu L. Effects of aluminum and extremely low frequency electromagnetic radiation on oxidative stress and memory in brain of mice. Biol Trace Elem Res. 156(1-3):243-252, 2013.

(E) (VT, AE, DRF) Di S, Tian Z, Qian A, Li J, Wu J, Wang Z, Zhang D, Yin D, Brandi ML, Shang P. Large gradient high magnetic field affects FLG29.1 cells differentiation to form osteoclast-like cells. Int J Radiat Biol. 88(11):806-813, 2012.

(NE) (VT, CE) Di Loreto S, Falone S, Caracciolo V, Sebastiani P, D'Alessandro A, Mirabilio A, Zimmitti V, Amicarelli F. Fifty hertz extremely low-frequency magnetic field exposure elicits redox and trophic response in rat-cortical neurons. J Cell Physiol. 219(2):334-343, 2009.

(E) (VO, CE, IOD) Dinčić M, Krstić DZ, Čolović MB, Nešović Ostojić J, Kovačević S, De Luka SR, Djordjević DM, Ćirković S, Brkić P, Todorović J. Modulation of rat synaptosomal ATPases and acetylcholinesterase activities induced by chronic exposure to the static magnetic field. Int J Radiat Biol. 94(11):1062-1071, 2018

(E) (VT, AE, IX) Ding GR, Nakahara T, Hirose H, Koyama S, Takashima Y, Miyakoshi J. Extremely low frequency magnetic fields and the promotion of H_2O_2-induced cell death in HL-60 cells. Int J Radiat Biol. 80(4):317-324, 2004.

(E) (VO, CE, IFR) Djordjevic NZ, Paunović MG, Peulić AS. Anxiety-like behavioural effects of extremely low-frequency electromagnetic field in rats. Environ Sci Pollut Res Int. 24(27):21693-21699, 2017.

Dodson CA, Hore PJ, Wallace MI. A radical sense of direction: signalling and mechanism in cryptochrome magnetoreception. Trends Biochem Sci. 38(9):435-446, 2013. (Review)

(E) (IV, AE, IFR, DFR, IAO, DAO, IOD) Dornelles EB, Goncalves BD, Schott KL, Barbisan F, Unfer TC, Glanzner WG, Machado AK, Cadona FC, Azzolin VF, Montano MA, Griner J, da Cruz IB. Cytotoxic effects of moderate static magnetic field exposure on human periphery blood mononuclear cells are influenced by Val16Ala-MnSOD gene polymorphism. Environ Sci Pollut Res Int. 24(5):5078-5088, 2017.

(E) (VO, CE, IFR, DAO, IX) Duan Y, Wang Z, Zhang H, He Y, Lu R, Zhang R, Sun G, Sun X. The preventive effect of lotus seedpod procyanidins on cognitive impairment and oxidative damage induced by extremely low frequency electromagnetic field exposure. Food Funct. 4(8):1252-1262, 2013.

(NE) (VT, AE) Duan W, Liu C, Zhang L, He M, Xu S, Chen C, Pi H, Gao P, Zhang Y, Zhong M, Yu Z, Zhou Z. Comparison of the genotoxic effects induced by 50 Hz extremely low-frequency electromagnetic fields and 1800 MHz radiofrequency electromagnetic fields in GC-2 cells. Radiat Res. 183(3):305-314, 2015.

(E) (VT, AE, IX, DFR) Duong CN, Kim JY. Exposure to electromagnetic field attenuates oxygen-glucose deprivation-induced microglial cell death by reducing intracellular Ca2+ and ROS. Int J Radiat Biol. 92(4):195-201, 2016.

(E) (IV, AE, CE, IFR, DFR, IAO) Ehnert S, Fentz AK, Schreiner A, Birk J, Wilbrand B, Ziegler P, Reumann MK, Wang H, Falldorf K, Nussler AK. Pulsed electromagnetic fields cause antioxidative defense mechanisms in human osteoblasts via induction of $\bullet O_2^-$ and H_2O_2. Sci Rep. 7(1):14544, 2017.

(E) (VO, CE, IOD, IAO) Emre M, Cetiner S, Zencir S, Unlukurt I, Kahraman I, Topcu Z. Oxidative stress and apoptosis in relation to exposure to magnetic field. Cell Biochem Biophys. 59(2):71-77, 2011.

(E) (VO, CE, IFR) Erdal N, Gürgül S, Tamer L, Ayaz L. Effects of long-term exposure of extremely low frequency magnetic field on oxidative/nitrosative stress in rat liver. J Radiat Res (Tokyo). 49(2):181-187, 2008.

(E) (VT, AE, IAO, IX) Errico Provenzano A, Amatori S, Nasoni MG, Persico G, Russo S, Mastrogiacomo AR, Gambarara A, Fanelli M. Effects of fifty-hertz electromagnetic fields on granulocytic differentiation of ATRA-treated acute promyelocytic leukemia NB4 cells. Cell Physiol Biochem. 46(1):389-400, 2018.

(E) (IV, AE, IAO, IX, MC) Falone S, Grossi MR, Cinque B, D'Angelo B, Tettamanti E, Cimini A, Di Ilio C, Amicarelli F. Fifty hertz extremely low-frequency electromagnetic field causes changes in redox and differentiative status in neuroblastoma cells. Int J Biochem Cell Biol. 39(11):2093-2106, 2007.

(E) (VO, CE, IAO, DAO) Falone S, Mirabilio A, Carbone MC, Zimmitti V, Di Loreto S, Mariggiò MA, Mancinelli R, Di Ilio C, Amicarelli F. Chronic exposure to 50 Hz magnetic fields causes a significant weakening of antioxidant defence systems in aged rat brain. Int J Biochem Cell Biol. 40(12):2762-2770, 2008.

(E) (VT, AE, IAO, IX) Falone S, Marchesi N, Osera C, Fassina L, Comincini S, Amadio M, Pascale A. Pulsed electromagnetic field (PEMF) prevents pro-oxidant effects of H_2O_2 in SK-N-BE(2) human neuroblastoma cells. Int J Radiat Biol. 92(5):281-286, 2016.

(E) (VT, AE, IAO) Falone S, Santini S Jr, Cordone V, Cesare P, Bonfigli A, Grannonico M, Di Emidio G, Tatone C, Cacchio M, Amicarelli F. Power frequency magnetic field promotes a more malignant phenotype in neuroblastoma cells via redox-related mechanisms. Sci Rep. 7(1):11470, 2017.

Falone S, Santini S Jr, Cordone V, Di Emidio G, Tatone C, Cacchio M, Amicarelli F. Extremely low-frequency magnetic fields and redox-responsive pathways linked to cancer drug resistance: Insights from co-exposure-based *In Vitro* studies. Front Public Health. 6:33, 2018. (Review)

(VT, AE, IFR, AO) Feng B, Qiu L, Ye C, Chen L, Fu Y, Sun W. Exposure to a 50-Hz magnetic field induced mitochondrial permeability transition through the ROS/GSK-3β signaling pathway. Int J Radiat Biol. 92:148-155, 2016a.

(E) (VT, AE, IFR) Feng B, Dai A, Chen L, Qiu L, Fu Y, Sun W. NADPH oxidase-produced superoxide mediated a 50-Hz magnetic field-induced epidermal growth factor receptor clustering. Int J Radiat Biol. 92:596-602, 2016b.

(E) (VT, AE, IFR, MC) Feng B, Ye C, Qiu L, Chen L, Fu Y, Sun W. Mitochondrial ROS release and subsequent Akt Activation potentially mediated the anti-apoptotic effect of a 50-Hz magnetic field on FL cells. Cell Physiol Biochem. 38(6):2489-2499, 2016c.

(E) (VO, CE, DAO) Fernie KJ, Bird DM. Evidence of oxidative stress in American kestrels exposed to electromagnetic fields. Environ Res. 86(2):198-207, 2001.

(E) (VT, AE, IX) Fiorani M, Biagiarelli B, Vetrano F, Guidi G, Dachà M, Stocchi V. In vitro effects of 50 Hz magnetic fields on oxidatively damaged rabbit red blood cells. Bioelectromagnetics. 18(2):125-131, 1997.

(E) (VT, AE, IFR) Fitzsimmons RJ, Gordon SL, Kronberg J, Ganey T, Pilla AA. A pulsing electric field (PEF) increases human chondrocyte proliferation through a transduction pathway involving nitric oxide signaling. J Orthop Res. 26(6):854-859, 2008.

(E) (VT, AE, IFR) Frahm J, Lantow M, Lupke M, Weiss DG, Simkó M. Alteration in cellular functions in mouse macrophages after exposure to 50 Hz magnetic fields. J Cell Biochem. 99(1):168-177, 2006.

(E) (VT, AE, IFR) Frahm J, Mattsson MO, Simkó M. Exposure to ELF magnetic fields modulate redox related protein expression in mouse macrophages. Toxicol Lett. 192(3):330-336, 2010.

(E) (VT, AE, IFR) Garip AI, Akan Z. Effect of ELF-EMF on number of apoptotic cells; correlation with reactive oxygen species and HSP. Acta Biol Hung. 61(2):158-167, 2010.

(E)(VO, CE, IAO, IX) Ghodbane S, Amara S, Arnaud J, Garrel C, Faure H, Favier A, Sakly M, Abdelmelek H. Effect of selenium pre-treatment on plasma antioxidant vitamins A (retinol) and E (α-tocopherol) in static magnetic field-exposed rats. Toxicol Ind Health. 27(10):949-955, 2011a.

(E) (VO, CE, IAO, DAO) Ghodbane S, Amara S, Garrel C, Arnaud J, Ducros V, Favier A, Sakly M, Abdelmelek H. Selenium supplementation ameliorates static magnetic field-induced disorders in antioxidant status in rat tissues. Environ Toxicol Pharmacol. 31(1):100-106, 2011b.

Ghodbane S, Lahbib A, Sakly M, Abdelmelek H. Bioeffects of static magnetic fields: oxidative stress, genotoxic effects, and cancer studies. Biomed Res Int. 2013:602987, 2013. (Review)

(E) (VO, CE, IX) Ghodbane S1, Amara S, Lahbib A, Louchami K, Sener A, Sakly M, Abdelmelek H. Vitamin E prevents glucose metabolism alterations induced by static magnetic field in rats. Environ Sci Pollut Res Int. 21(22):12731-12738, 2014.

(E) (VO, CE, IAO, AO) Ghodbane S, Ammari M, Lahbib A, Sakly M, Abdelmelek H. Static magnetic field exposure-induced oxidative response and caspase-independent apoptosis in rat liver: effect of selenium and vitamin E supplementations. Environ Sci Pollut Res Int. 22(20):16060-16066, 2015a.

(E) (VO, CE, IAO, IOD, AO) Ghodbane S, Lahbib A, Ammari M, Sakly M, Abdelmelek H. Does static magnetic field-exposure induced oxidative stress and apoptosis in rat kidney and muscle? Effect of vitamin E and selenium supplementations. Gen Physiol Biophys. 34(1):23-32, 2015b.

(NE)(VT, AE, IX) Giorgi G, Lecciso M, Capri M, Lukas Yani S, Virelli A, Bersani F, Del Re B. An evaluation of genotoxicity in human neuronal-type cells subjected to oxidative stress under an extremely low frequency pulsed magnetic field. Mutat Res Genet Toxicol Environ Mutagen. 775-776:31-37, 2014.

(E) (VT, AE, IOD, IX) Giorgi G, Pirazzini C, Bacalini MG, Giuliani C, Garagnani P, Capri M, Bersani F, Del Re B. Assessing the combined effect of extremely low-frequency magnetic field exposure and oxidative stress on LINE-1 promoter methylation in human neural cells. Radiat Environ Biophys. 56(2):193-200, 2017.

(E) (VO, CE, DOD, IAO) Glinka M, Sieroń A, Birkner E, Cieślar G. Influence of extremely low-frequency magnetic field on the activity of antioxidant enzymes during skin wound healing in rats. Electromagn Biol Med. 32(4):463-470, 2013.

(E) (IV, AE, DAO) Glinka M, Gawron S, Sieroń A, Pawłowska-Góral K, Cieślar G, Sieroń K. Impact of static magnetic field on the antioxidant defence system of mice fibroblasts. Biomed Res Int. 2018:5053608, 2018.

Ghodbane S, Lahbib A, Sakly M, Abdelmelek H. Bioeffects of static magnetic fields: oxidative stress, genotoxic effects, and cancer studies. Biomed Res Int. 2013:602987, 2013. (Review)

(E) (VO, CE, IOD) Gok DK, Akpinar D, Hidisoglu E, Ozen S, Agar A, Yargicoglu P. The developmental effects of extremely low frequency electric fields on visual and somatosensory evoked potentials in adult rats. Electromagn Biol Med. 35(3):245-259, 2016.

(E) (VT, CE, IRF, IOD, DAO) Goraca A, Ciejka E, Piechota A. Effects of extremely low frequency magnetic field on the parameters of oxidative stress in heart. J Physiol Pharmacol. 61(3):333-338, 2010.

(E) (VO, CE, IFR, IOD, DAO) Guler G, Turkozer Z, Tomruk A, Seyhan N. The protective effects of N-acetyl-L-cysteine and epigallocatechin-3-gallate on electric field-induced hepatic oxidative stress. Int J Radiat Biol. 84(8):669-680, 2008.

(NE) (VO, CE) Güler G, Türközer Z, Ozgur E, Tomruk A, Seyhan N, Karasu C. Protein oxidation under extremely low frequency electric field in guinea pigs. Effect of N-acetyl-L-cysteine treatment. Gen Physiol Biophys. 28(1):47-55, 2009a.

(NE) (VO, CE) Güler G, Türközer Z, Ozgur E, Seyhan N. Antioxidants alleviate electric field-induced effects on lung tissue based on assays of heme oxygenase-1, protein carbonyl content, malondialdehyde, nitric oxide, and hydroxyproline. Sci Total Environ. 407(4):1326-1332, 2009b.

(E) (VT, AE, IAO, IFC, IX) Hajipour Verdom B, Abdolmaleki P, Behmanesh M. The static magnetic field remotely boosts the efficiency of doxorubicin through modulating ROS behaviors. Sci Rep. 8(1):990, 2018.

(E) (VO, CE, IAO, LI) Hajnorouzi A, Vaezzadeh M, Ghanati F, Jamnezhad H, Nahidian B. Growth promotion and a decrease of oxidative stress in maize seedlings by a combination of geomagnetic and weak electromagnetic fields. J Plant Physiol. 168(10):1123-1128, 2011.

(E) (VO, AE, IOD, IAO) Hanini R, Chatti A, Ghorbel SB, Landoulsi A. Role of SOD gene in response to static magnetic fields in Pseudomonas aeruginosa. Curr Microbiol. 74(8):930-937, 2017.

(NE) (VO, CE) Harakawa S, Inoue N, Hori T, Tochio K, Kariya T, Takahashi K, Doge F, Suzuki H, Nagasawa H. Effects of a 50 Hz electric field on plasma lipid peroxide level and antioxidant activity in rats. Bioelectromagnetics. 26(7):589-594, 2005.

(E) (VO, CE, IOD, DAO) Hashish AH, El-Missiry MA, Abdelkader HI, Abou-Saleh RH. Assessment of biological changes of continuous whole body exposure to static magnetic field and extremely low frequency electromagnetic fields in mice. Ecotoxicol Environ Saf. 71(3):895-902. 2008.

(E) (VT, AE, IOD, IFR, IAO, DAO) Henrykowska G, Jankowski W, Pacholski K, Lewicka M, Smigielski J, Dziedziczak-Buczyńska M, Buczyński A. The effect of 50 Hz magnetic field of different shape on oxygen metabolism in blood platelets: in vitro studies. Int J Occup Med Environ Health. 22(3):269-276, 2009.

(NE) (VT, AE) Hong MN, Han NK, Lee HC, Ko YK, Chi SG, Lee YS, Gimm YM, Myung SH, Lee JS. Extremely low frequency magnetic fields do not elicit oxidative stress in MCF10A cells. Radiat Res. 53(1):79-86, 2012.

(E) (HU, CE, IOD, IAO) Hosseinabadi MB, Khanjani N. The effect of extremely low-frequency electromagnetic fields on the prevalence of musculoskeletal disorders and the role of oxidative stress. Bioelectromagnetics. 2019 Jun 18. doi: 10.1002/bem.22198. [Epub ahead of print]

(E) (VT, AE, IFR) Höytö A, Herrala M, Luukkonen J, Juutilainen J, Naarala J. Cellular detection of 50 Hz magnetic fields and weak blue light: effects on superoxide levels and genotoxicity. Int J Radiat Biol. 7:1-7, 2017.

(E) (VO, CE, DFR) Hu Y, Lai J, Wan B, Liu X, Zhang Y, Zhang J, Sun D, Ruan G, Liu E, Liu GP, Chen C, Wang DW. Long-term exposure to ELF-MF ameliorates cognitive deficits and attenuates tau hyperphosphorylation in 3xTg AD mice. Neurotoxicology 53:290-300, 2016.

(E) (VT, AE, IX, AO) Jajte J, Zmyślony M, Palus J, Dziubałtowska E, Rajkowska E. Protective effect of melatonin against in vitro iron ions and 7 mT 50 Hz magnetic field-induced DNA damage in rat lymphocytes. Mutat Res. 483(1-2):57-64, 2001.

(E) (VT, AE, IX) Jajte J, Grzegorczyk J, Zmyślony M, Rajkowska E. Effect of 7 mT static magnetic field and iron ions on rat lymphocytes: apoptosis, necrosis and free radical processes. Bioelectrochemistry. 57(2):107-111, 2002.

(E) (VT, AE, IX, AO) Jajte J, Zmyślony M, Rajkowska E. [Protective effect of melatonin and vitamin E against prooxidative action of iron ions and static magnetic field]. Med Pr. 54(1):23-28, 2003. [Article in Polish]

(E) (VO, CE, IFR, IOD, IAO) Jelenković A, Janać B, Pesić V, Jovanović DM, Vasiljević I, Prolić Z. Effects of extremely low-frequency magnetic field in the brain of rats. Brain Res Bull. 68(5):355-360, 2006.

(E) (VO, AE, IFR) Jeong JH, Kum C, Choi HJ, Park ES, Sohn UD. Extremely low frequency magnetic field induces hyperalgesia in mice modulated by nitric oxide synthesis. Life Sci. 78(13):1407-1412, 2006.

(NE) (VT, AE) Jin H, Yoon HE, Lee JS, Kim JK, Myung SH, Lee YS. Effects on g2/m phase cell cycle distribution and aneuploidy formation of exposure to a 60 Hz electromagnetic field in combination with ionizing radiation or hydrogen peroxide in l132 nontumorigenic human lung epithelial cells. Korean J Physiol Pharmacol. 19(2):119-124, 2015.

(NE) (VT, AE) Jin YB, Kang GY, Lee JS, Choi JI, Lee JW, Hong SC, Myung SH, Lee YS. Effects on micronuclei formation of 60-Hz electromagnetic field exposure with ionizing radiation, hydrogen peroxide, or c-Myc overexpression. Int J Radiat Biol. 88(4):374-80, 2012.

(NE) (VT, AE) Jin YB, Choi SH, Lee JS, Kim JK, Lee JW, Hong SC, Myung SH, Lee YS. Absence of DNA damage after 60-Hz electromagnetic field exposure combined with ionizing radiation, hydrogen peroxide, or c-Myc overexpression. Radiat Environ Biophys. 53(1):93-101, 2014.

(E) (VO, CE, IOD, DAO) Jouni FJ, Abdolmaleki P, Ghanati F. Oxidative stress in broad bean (Vicia faba L.) induced by static magnetic field under natural radioactivity. Mutat Res. 741(1-2):116-121, 2012.

(E) (VT, AE, IFR, IX) Kamalipooya S, Abdolmaleki P, Salemi Z, Javani Jouni F, Zafari J, Soleimani H. Simultaneous application of cisplatin and static magnetic field enhances oxidative stress in HeLa cell line. In Vitro Cell Dev Biol Anim. 53(9):783-790, 2017.

(E) (VO, CE, IOD) Kantar Gok D, Akpinar D, Yargicoglu P, Ozen S, Aslan M, Demir N, Derin N, Agar A. Effects of extremely low-frequency electric fields at different intensities and exposure durations on mismatch negativity. Neuroscience. 272C:154-166, 2014.

(E) (VO, CE, IFR, IAO, IOD) Karimi SA, Salehi I, Shykhi T, Zare S, Komaki A. Effects of exposure to extremely low-frequency electromagnetic fields on spatial and passive avoidance learning and memory, anxiety-like behavior and oxidative stress in male rats. Behav Brain Res. 359:630-638, 2019.

(E) (VO, AE, IFR) Kavaliers M, Choleris E, Prato FS, Ossenkopp K. Evidence for the involvement of nitric oxide and nitric oxide synthase in the modulation of opioid-induced antinociception and the inhibitory effects of exposure to 60-Hz magnetic fields in the land snail. Brain Res. 809(1):50-57, 1998.

(NE) (VT, AE) Kesari KK, Luukkonen J, Juutilainen J, Naarala J. Genomic instability induced by 50 Hz magnetic fields is a dynamically evolving process not blocked by antioxidant treatment. Mutat Res Genet Toxicol Environ Mutagen. 794:46-51, 2015.

(E) (VT, AE, IFR) Kesari KK, Juutilainen J, Luukkonen J, Naarala J. Induction of micronuclei and superoxide production in neuroblastoma and glioma cell lines exposed to weak 50 Hz magnetic fields. J R Soc Interface. 2016 Jan; 13(114). pii: 20150995. doi: 10.1098/rsif.2015.0995.

(E) (VT, AE, IFR) Khadir R, Morgan JL, Murray JJ. Effects of 60 Hz magnetic field exposure on polymorphonuclear leukocyte activation. Biochim Biophys Acta. 1472(1-2):359-367, 1999.

(E) (VT, AE, IFR, AO) Kim SJ, Jang YW, Hyung KE, Lee DK, Hyun KH, Jeong SH, Min KH, Kang W, Jeong JH, Park SY, Hwang KW. Extremely low-frequency electromagnetic field exposure enhances inflammatory response and inhibits effect of antioxidant in RAW 264.7 cells. Bioelectromagnetics. 38(5):374-385, 2017.

(E) (VT,AE, IX, MC) Kimsa-Dudek M, Synowiec-Wojtarowicz A, Derewniuk M, Gawron S, Paul-Samojedny M, Kruszniewska-Rajs C, Pawłowska-Góral K. Impact of fluoride and a static magnetic field on the gene expression that is associated with the antioxidant defense system of human fibroblasts. Chem Biol Interact. 287:13-19, 2018.

Kıvrak EG, Yurt KK, Kaplan AA, Alkan I, Altun G. Effects of electromagnetic fields exposure on the antioxidant defense system. J Microsc Ultrastruct. 5(4):167-176, 2017. (Review)

(E) (VT, AE, IFR, AO) Koh EK, Ryu BK, Jeong DY, Bang IS, Nam MH, Chae KS. A 60-Hz sinusoidal magnetic field induces apoptosis of prostate cancer cells through reactive oxygen species. Int J Radiat Biol. 84(11):945-955, 2008.

(E) (VT, AE, IX) Koyama S, Nakahara T, Hirose H, Ding GR, Takashima Y, Isozumi Y, Miyakoshi J. ELF electromagnetic fields increase hydrogen peroxide (H_2O_2)-induced mutations in pTN89 plasmids. Mutat Res. 560(1):27-32, 2004.

(E) (VT, AE, IX) Koyama S, Sakurai T, Nakahara T, Miyakoshi J. Extremely low frequency (ELF) magnetic fields enhance chemically induced formation of apurinic/apyrimidinic (AP)sites in A172 cells. Int J Radiat Biol. 84(1):53-59, 2008.

(E) (VO, AE, IAO, DAO, IOD) Kthiri A, Hidouri S, Wiem T, Jeridi R, Sheehan D, Landouls A. Biochemical and biomolecular effects induced by a static magnetic field in Saccharomyces cerevisiae: Evidence for oxidative stress. PLoS One. 14(1):e0209843, 2019.

(E) (HU, CE, IFR) Kunt H, Şentürk İ, Gönül Y, Korkmaz M, Ahsen A, Hazman Ö, Bal A, Genç A, Songur A. Effects of electromagnetic radiation exposure on bone mineral density, thyroid, and oxidative stress index in electrical workers. OncoTargets and Therapy. 2016(9):745-754, 2016.

(E) (VT, CE, IX) Kurzeja E, Synowiec-Wojtarowicz A, Stec M, Glinka M, Gawron S, Pawłowska-Góral K. Effect of a static magnetic fields and fluoride ions on the antioxidant defense system of mice fibroblasts. Int J Mol Sci.14(7):15017-15028, 2013.

(E) (VO, CE, IFR, IOD, DAO) Kuzay D, Ozer C, Sirav B, Canseven AG, Seyhan N. Oxidative effects of extremely low frequency magnetic field and radio frequency radiation on testes tissues of diabetic and healthy rats. Bratisl Lek Listy. 118(5):278-282, 2017.

Lahbib A, Ghodbane S, Sakly M, Abdelmelek H. Vitamins and glucose metabolism: The role of static magnetic fields. Int J Radiat Biol. 90(12):1240-1245, 2014. (Review)

(E) (VO, AE, AO) Lai H, Singh NP. Melatonin and N-tert-butyl-alpha-phenylnitrone block 60-Hz magnetic field-induced DNA single and double strand breaks in rat brain cells. J Pineal Res. 22(3):152-162, 1997.

(E) (VO, AE, AO) Lai H, Singh NP. Magnetic-field-induced DNA strand breaks in brain cells of the rat. Environ Health Perspect. 112(6):687-694, 2004.

(E)(VT, AE, AO) Lai HC, Chan HW, Singh NP. Effects of radiation from a radiofrequency i dentification (RFID) microchip on human cancer cells. Int J Radiat Biol. 2016;92(3):156-161, 2016.

(E) (VO, AE, IOD, IAO) Lee BC, Johng HM, Lim JK, Jeong JH, Baik KY, Nam TJ, Lee JH, Kim J, Sohn UD, Yoon G, Shin S, Soh KS. Effects of extremely low frequency magnetic field on the antioxidant defense system in mouse brain: a chemiluminescence study. J Photochem Photobiol B. 73(1-2):43-48, 2004.

(NE) (VT, AE) Lee HJ, Jin YB, Lee JS, Choi JI, Lee JW, Myung SH, Lee YS. Combined effects of 60 Hz electromagnetic field exposure with various stress factors on cellular transformation in NIH3T3 cells. Bioelectromagnetics. 33(3):207-214, 2012.

(E) (VT, AE, IRF) Lee HM, Kwon UH, Kim H, Kim HJ, Kim B, Park JO, Moon ES, Moon SH. Pulsed electromagnetic field stimulates cellular proliferation in human intervertebral disc cells. Yonsei Med J. 51(6):954-959, 2010.

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. 2014:169459, 2014. (Review)

(E) (VT, AE, IOD, IAO) Lewicka M, Henrykowska GA, Pacholski K, Szczęsny A, Dziedziczak-Buczyńska M, Buczyński A. The impact of electromagnetic radiation of different parameters on platelet oxygen metabolism - in vitro studies. Adv Clin Exp Med. 24(1):31-35, 2015.

(NE) (HU, CE) Li L, Xiong DF, Liu JW, Li ZX, Zeng GC, Li HL. A cross-sectional study on oxidative stress in workers exposed to extremely low frequency electromagnetic fields. Int J Radiat Biol. 91(5):420-425, 2015.

(E) (VO, AE, CE, IAO) Li SS, Zhang ZY, Yang CJ, Lian HY, Cai P. Gene expression and reproductive abilities of male Drosophila melanogaster subjected to ELF-EMF exposure. Mutat Res. 758(1-2):95-103, 2013.

(E) (IV AE, IFR, IAO) Lian HY, Lin KW, Yang C, Cai P. Generation and propagation of yeast prion [URE3] are elevated under electromagnetic field. Cell Stress Chaperones. 23(4):581-594, 2018.

(E) (VT, AE, AO) Liu DD, Ren Z, Yang G, Zhao QR, Mei YA. Melatonin protects rat cerebellar granule cells against electromagnetic field-induced increases in Na^+ currents through intracellular Ca^{2+} release. J Cell Mol Med. 18(6):1060-1070, 2014.

(E) (VO, CE, IOD, DAO) Liu Y, Weng E, Zhang Y, Hong R. [Effects of extremely low frequency electromagnetic field and its combination with lead on the antioxidant system in mouse] Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi. 20(4):263-265, 2002. [Article in Chinese]

(E) (VO, CE, IOD, DAO, AO) Luo X, Chen M, Duan Y, Duan W, Zhang H, He Y, Yin C, Sun G, Sun X. Chemoprotective action of lotus seedpod procyanidins on oxidative stress in mice induced by extremely low-frequency electromagnetic field exposure. Biomed Pharmacother. 82:640-648, 2016.

(E) (VO, AE, DAO) Luo K, Luo C, Li G, Yao X, Gao R, Hu Z, Zhang G, Zhao H. High-voltage electrostatic field-induced oxidative stress: Characterization of the physiological effects in Sitobion avenae (Hemiptera: Aphididae) across multiple generations. Bioelectromagnetics. 40(1):52-61, 2019.

(E) (VO, AC, IFR) Lupke M, Rollwitz J, Simkó M. Cell activating capacity of 50 Hz magnetic fields to release reactive oxygen intermediates in human umbilical cord blood-derived monocytes and in Mono Mac 6 cells. Free Radic Res. 38(9):985-993, 2004.

(E) (VT, AE, IFR) Luukkonen J, Liimatainen A, Juutilainen J, Naarala J. Induction of genomic instability, oxidative processes, and mitochondrial activity by 50 Hz magnetic fields in human SH-SY5Y neuroblastoma cells. Mutat Res. 760:33-41, 2014.

(E) (VT, AE, MC) Mahmoudinasab H, Sanie-Jahromi F, Saadat M. Effects of extremely low-frequency electromagnetic field on expression levels of some antioxidant genes in human MCF-7 cells. Mol Biol Res Commun. 5(2):77-85. 2016.

(E) (VT, AE, IAO, IX) Mahmoudinasab H, Saadat M. Electromagnetic field could protect SH-SY5Y cells against cisplatin cytotoxicity, but not MCF-7 cells. DNA Cell Biol. 37(4):330-335, 2018a.

(E) (VT, AE, IX, MC) Mahmoudinasab H, Saadat M. Expressions of some antioxidant genes in SH-SY5Y cells treated with β-lapachone, morphine and electromagnetic field. Mol Biol Rep. 45(3):379-387, 2018b.

(E) (VO, CE, TOD, DAO) Maliszewska J, Marciniak P, Kletkiewicz H, Wyszkowska J, Nowakowska A, Rogalska J. Electromagnetic field exposure (50 Hz) impairs response to noxious heat in American cockroach. J Comp Physiol A Neuroethol Sens Neural Behav Physiol. 2018 May 2. doi: 10.1007/s00359-018-1264-2. [Epub ahead of print]

(E) (VO, CE, IFR, IOD) Manikonda PK, Rajendra P, Devendranath D, Gunasekaran B, Channakeshava, Aradhya SR, Sashidhar RB, Subramanyam C. Extremely low frequency magnetic fields induce oxidative stress in rat brain. Gen Physiol Biophys. 33(1):81-90, 2014.

(E) (VT AE, IFR, AO) Mannerling AC, Simkó M, Mild KH, Mattsson MO. Effects of 50-Hz magnetic field exposure on superoxide radical anion formation and HSP70 induction in human K562 cells. Radiat Environ Biophys. 49(4):731-741, 2010.

(NE) (VT, AE) Markkanen A, Naarala J, Juutilainen J. A Study on the effects of 50 Hz magnetic fields on UV-induced radical reactions in murine fibroblasts. J Radiat Res (Tokyo). 51(5):609-613, 2010.

(E) (VT, AE, AO) Martínez MA, Úbeda A, Moreno J, Trillo MÁ. Power frequency magnetic fields affect the p38 MAPK-mediated regulation of NB69 cell proliferation implication of free radicals. Int J Mol Sci. 17(4):510, 2016.

(E) (VO, AE, DAO) Martínez-Sámano J, Torres-Durán PV, Juárez-Oropeza MA, Elías-Viñas D, Verdugo-Díaz L. Effects of acute electromagnetic field exposure and movement restraint on antioxidant system in liver, heart, kidney and plasma of Wistar rats: a preliminary report. Int J Radiat Biol. 86(12):1088-1094, 2010.

(E) (VO, AE, DAO) Martínez-Sámano J, Torres-Durán PV, Juárez-Oropeza MA, Verdugo-Díaz L. Effect of acute extremely low frequency electromagnetic field exposure on the antioxidant status and lipid levels in rat brain. Arch Med Res. 43(3):183-189, 2012.

(E) (VO, CE, IOD) Martínez-Sámano J, Flores-Poblano A, Verdugo-Díaz L, Juárez-Oropeza MA, Torres-Durán PV. Extremely low frequency electromagnetic field exposure and restraint stress induce changes on the brain lipid profile of Wistar rats. BMC Neurosci. 19(1):31, 2018.

(E) (VT, AE, AO) Martino CF. Static magnetic field sensitivity of endothelial cells. Bioelectromagnetics. 32(6):506-508, 2011.

(E) (VT, AE, IFR, LI) Martino CF, Castello PR. Modulation of hydrogen peroxide production in cellular systems by low level magnetic fields. PLoS One. 6(8):e22753, 2011.

(E) (VO, CE, DOD, IAO, IX) Medina-Fernandez FJ, Escribano BM, Agüera E, Aguilar-Luque M, Feijoo M, Luque E, Garcia-Maceira FI, Pascual-Leone A, Drucker-Colin R, Tunez I. Effects of transcranial magnetic stimulation on oxidative stress in experimental autoimmune encephalomyelitis. Free Radic Res. 51(5):460-469, 2017.

(E) (VO, CE, DOD, IAO, IX) Medina-Fernandez FJ, Escribano BM, Luque E, Caballero-Villarraso J, Gomez-Chaparro JL, Feijoo M, Garcia-Maceira FI, Pascual-Leone A, Drucker-Colin R, Tunez I. Comparative of transcranial magnetic stimulation and other treatments in experimental autoimmune encephalomyelitis. Brain Res Bull. 137:140-145, 2018.

Medina-Fernández FJ, Escribano BM, Padilla-Del-Campo C, Drucker-Colín R, Pascual-Leone Á, Túnez I. Transcranial magnetic stimulation as an antioxidant. Free Radic Res. 52(4):381-389, 2018. (Review)

(E) (VT, AE, IFR, MC) Merla C, Liberti M, Consales C, Denzi A, Apollonio F, Marino C, Benassi B. Evidences of plasma membrane-mediated ROS generation upon ELF exposure in neuroblastoma cells supported by a computational multiscale approach. Biochim Biophys Acta Biomembr. 1861(8):1446-1457, 2019.

(NE) (VT, AE) Messiha HL, Wongnate T, Chaiyen P, Jones AR, Scrutton NS. Magnetic field effects as a result of the radical pair mechanism are unlikely in redox enzymes. J R Soc Interface. 2015 Feb 6; 12(103). pii: 20141155. doi: 10.1098/rsif.2014.1155.

(E) (VO, CE, DAO) Miao X, Wang Y, Lang H, Lin Y, Guo Q, Yang M, Guo J, Zhang Y, Zhang J, Liu J, Liu Y, Zeng L, Guo G. Preventing electromagnetic pulse irradiation damage on testis using selenium-rich Cordyceps fungi. A preclinical study in young male mice. OMICS. 21(2):81-89, 2017.

(E) (VT, AE, IFR, IAO) Miliša M, Đikić D, Mandić T, Grozić D, Čolić I, Ostojić A. Response of aquatic protists to electric field exposure. Int J Radiat Biol. 93(8):818-830, 2017.

(E) (VT, AE, IFR) Mohammadi F, Ghanati F, Sharifi M, Chashmi NA. On the mechanism of the cell cycle control of suspension-cultured tobacco cells after exposure to static magnetic field. Plant Sci. 277:139-144. 2018.

Montoya RD. Magnetic fields, radicals and cellular activity. Electromagn Biol Med. 36(1):102-113, 2017. (Review)

(E) (VT, AE, CE, IFR, IAO, DAO) Morabito C, Guarnieri S, Fanò G, Mariggiò MA. Effects of acute and chronic low frequency electromagnetic field exposure on PC12 cells during neuronal differentiation. Cell Physiol Biochem. 26(6):947-958, 2010a.

(E) (VT, AE, IFR, IAO) Morabito C, Rovetta F, Bizzarri M, Mazzoleni G, Fanò G, Mariggiò MA. Modulation of redox status and calcium handling by extremely low frequency electromagnetic fields in C2C12 muscle cells: A real-time, single-cell approach. Free Radic Biol Med. 48(4):579-589, 2010b.

(E) (VT, AE, IFR) Naarala J, Kesari KK, McClure I, Chavarriaga C, Juutilainen J, Martino CF. Direction-dependent effects of combined static and ELF magnetic fields on cell proliferation and superoxide radical production. Biomed Res Int. 2017:5675086, 2017.

(NE) (VT, AE) Nakayama M, Nakamura A, Hondou T, Miyata H. Evaluation of cell viability, DNA single-strand breaks, and nitric oxide production in LPS-stimulated macrophage RAW264 exposed to a 50-Hz magnetic field. Int J Radiat Biol. 92(10):583-589, 2016.

(E) (VT, AE, IFR) Noda Y, Mori A, Liburdy RP, Packer L. Pulsed magnetic fields enhance nitric oxide synthase activity in rat cerebellum. Pathophysiology. 7(2):127-130, 2000.

Okano H. Effects of static magnetic fields in biology: role of free radicals. Front Biosci. 13:6106-6125, 2008. (Review)

(E) (VT, AE, IAO) Osera C, Fassina L, Amadio M, Venturini L, Buoso E, Magenes G, Govoni S, Ricevuti G, Pascale A. Cytoprotective response induced by electromagnetic stimulation on SH-SY5Y human neuroblastoma cell line. Tissue Eng Part A. 17(19-20):2573-2582, 2011.

(E) (VT, AE, IAO, IX) Osera C, Amadio M, Falone S, Fassina L, Magenes G, Amicarelli F, Ricevuti G, Govoni S, Pascale A. Pre-exposure of neuroblastoma cell line to pulsed electromagnetic field prevents H_2O_2 -induced ROS production by increasing MnSOD activity. Bioelectromagnetics. 36(3):219-232, 2015.

(E) (VT, AE, IFR) Pakhomova ON, Khorokhorina VA, Bowman AM, Rodaitė-Riševičienė R, Saulis G, Xiao S, Pakhomov AG. Oxidative effects of nanosecond pulsed electric field exposure in cells and cell-free media. Arch Biochem Biophys. 527(1):55-64, 2012.

(E) (VO, AE, IOD, DAO) Pandir D, Sahingoz R. Magnetic field-induced oxidative stress and DNA damage in Mediterranean flour moth Ephestia kuehniella Zeller (Lepidoptera: Pyralidae) larvae. J Pest Sci 87(1): 79-87, 2014.

(E) (VT, AE, IFR) Park JE, Seo YK, Yoon HH, Kim CW, Park JK, Jeon S. Electromagnetic fields induce neural differentiation of human bone marrow derived mesenchymal stem cells via ROS mediated EGFR activation. Neurochem Int. 62(4):418-424, 2013.

(E) (VT, AE, IFR, DFR, IAO, DAO) Patruno A, Amerio P, Pesce M, Vianale G, Di Luzio S, Tulli A, Franceschelli S, Grilli A, Muraro R, Reale M. Extremely low frequency electromagnetic fields modulate expression of inducible nitric oxide synthase, endothelial nitric oxide synthase and cyclooxygenase-2 in the human keratinocyte cell line HaCat: potential therapeutic effects in wound healing. Br J Dermatol. 162(2):258-266, 2010.

(E) (VT, AE, IAO, IFR) Patruno A, Tabrez S, Amerio P, Pesce M, Vianale G, Franceschelli S, Grilli A, Kamal MA, Reale M. Kinetic study on the effects of extremely low frequency electromagnetic field on catalase, cytochrome P450 and inducible nitric oxide synthase in human HaCaT and THP-1 cell lines. CNS Neurol Disord Drug Targets. 10(8):936-944, 2011.

(E) (VT, AE, IFR, DAO) Patruno A, Pesce M, Marrone A, Speranza L, Grilli A, De Lutiis MA, Felaco M, Reale M. Activity of matrix metallo proteinases (MMPs) and the tissue inhibitor of MMP (TIMP)-1 in electromagnetic field-exposed THP-1 cells. J Cell Physiol. 227(6):2767-2774, 2012.

(E) (VT, AE, IAO) Patruno A, Tabrez S, Pesce M, Shakil S, Kamal MA, Reale M. Effects of extremely low frequency electromagnetic field (ELF-EMF) on catalase, cytochrome P450 and nitric oxide synthase in erythro-leukemic cells. Life Sci. 121:117-123, 2015.

(E) (IV, AE, IFR) Pilla AA.Electromagnetic fields instantaneously modulate nitric oxide signaling in challenged biological systems. Biochem Biophys Res Commun. 426(3):330-333, 2012.

(E) (VO, CE, IAO, IX) Politański P, Rajkowska E, Pawlaczyk-Łuszczyńska M, Dudarewicz A, Wiktorek-Smagur A, Sliwińska-Kowalska M, Zmyślony M. Static magnetic field affects oxidative stress in mouse cochlea. Int J Occup Med Environ Health. 23(4):377-384, 2010.

(E) (VT, AE, DFR, IFR) Poniedzialek B, Rzymski P, Nawrocka-Bogusz H, Jaroszyk F, Wiktorowicz K. The effect of electromagnetic field on reactive oxygen species production in human neutrophils in vitro. Electromagn Biol Med. 32(3):333-341, 2013a.

(E) (VT, AE, DFR, IFR) Poniedziałek B, Rzymski P, Karczewski J, Jaroszyk F, Wiktorowicz K. Reactive oxygen species (ROS) production in human peripheral blood neutrophils exposed in vitro to static magnetic field. Electromagn Biol Med. 32(4):560-568, 2013b.

(E) (VT, AE, IFR) Pooam M, Nakayama M, Nishigaki C, Miyata H. Effect of 50-Hz sinusoidal magnetic field on the production of superoxide anion and the expression of heat-shock protein 70 in RAW264 cells. Int J Chem 9:23-36, 2017.

(E) (VT AE, IFR) Potenza L, Martinelli C, Polidori E, Zeppa S, Calcabrini C, Stocchi L, Sestili P, Stocchi V. Effects of a 300 mT static magnetic field on human umbilical vein endothelial cells. Bioelectromagnetics. 31(8):630-639, 2010.

(E) (VO, CE, IOD, IAO) Rageh MM, El-Gebaly RH, El-Bialy NS. Assessment of genotoxic and cytotoxic hazards in brain and bone marrow cells of newborn rats exposed to extremely low-frequency magnetic field. J Biomed Biotechnol. 2012:716023, 2012.

(E) (HU, AE, DOD) Raggi F, Vallesi G, Rufini S, Gizzi S, Ercolani E, Rossi R. ELF magnetic therapy and oxidative balance. Electromagn Biol Med. 27(4):325-339, 2008.

(E) (VO, AE, IAO) Rajabbeigi E, Ghanati F, Abdolmaleki P, Payez A. Antioxidant capacity of parsley cells (Petroselinum crispum L.) in relation to iron-induced ferritin levels and static magnetic field. Electromagn Biol Med. 32(4):430-441, 2013.

(E) (VO, CE, IX) Rauš Balind S, Selaković V, Radenović L, Prolić Z, Janać B. Extremely low frequency magnetic field (50 Hz, 0.5 mT) reduces oxidative stress in the brain of gerbils submitted to global cerebral ischemia. PLoS One. 9(2):e88921, 2014.

(E) (VT, AE, IAO) Reale M, De Lutiis MA, Patruno A, Speranza L, Felaco M, Grilli A, Macrì MA, Comani S, Conti P, Di Luzio S. Modulation of MCP-1 and iNOS by 50-Hz sinusoidal electromagnetic field. Nitric Oxide. 15(1):50-57, 2006.

(E) (VT, AE, IFR) Reale M, Kamal MA, Patruno A, Costantini E, D'Angelo C, Pesce M, Greig NH. Neuronal cellular responses to extremely low frequency electromagnetic field exposure: implications regarding oxidative stress and neurodegeneration. PLoS One. 9(8):e104973, 2014.

(E) (VO, CE, LI, IAO, DAO) Regoli F, Gorbi S, Machella N, Tedesco S, Benedetti M, Bocchetti R, Notti A, Fattorini D, Piva F, Principato G. Pro-oxidant effects of extremely low frequency electromagnetic fields in the land snail Helix aspersa. Free Radic Biol Med. 39(12):1620-1628, 2005.

(E) (VT, AE, IFR) Rollwitz J, Lupke M, Simkó M. Fifty-hertz magnetic fields induce free radical formation in mouse bone marrow-derived promonocytes and macrophages. Biochim Biophys Acta. 1674(3):231-238, 2004.

(NE) (IV, CE) Romeo S, Sannino A, Scarfì MR, Massa R, d'Angelo R, Zeni O. Lack of effects on key cellular parameters of MRC-5 human lung fibroblasts exposed to 370 mT static magnetic field. Sci Rep. 6:19398, 2016.

(E) (VT, AE, IFR) Roy S, Noda Y, Eckert V, Traber MG, Mori A, Liburdy R, Packer L. The phorbol 12-myristate 13-acetate (PMA)-induced oxidative burst in rat peritoneal neutrophils is increased by a 0.1 mT (60 Hz) magnetic field. FEBS Lett. 376(3):164-166, 1995.

(E) (VT, AE, IFR) Sadeghipour R, Ahmadian S, Bolouri B, Pazhang Y, Shafiezadeh M. Effects of extremely low-frequency pulsed electromagnetic fields on morphological and biochemical properties of human breast carcinoma cells (T47D). Electromagn Biol Med. 31(4):425-435, 2012.

(E) (VT, CE, IOD, IAO, DAO) Sahebjamei H, Abdolmaleki P, Ghanati F. Effects of magnetic field on the antioxidant enzyme activities of suspension-cultured tobacco cells. Bioelectromagnetics. 28(1):42-47, 2007.

(E) (VO, CE, IFR) Salunke BP, Umathe SN, Chavan JG. Experimental evidence for involvement of nitric oxide in low frequency magnetic field induced obsessive compulsive disorder-like behavior. Pharmacol Biochem Behav. 122:273-278, 2014.

Santini SJ, Cordone V, Falone S, Mijit M, Tatone C, Amicarelli F, Di Emidio G. Role of mitochondria in the oxidative stress induced by electromagnetic fields: focus on reproductive systems. Oxid Med Cell Longev. 2018:5076271, 2018. (Review)

(E) (VO. CE. IOD, DAO) Seif F, Bayatiani MR, Ansarihadipour H, Habibi G, Sadelaji S. Protective properties of Myrtus communis extract against oxidative effects of extremely low-frequency magnetic fields on rat plasma and hemoglobin. Int J Radiat Biol. 2018 Nov 29:1-22. doi: 10.1080/09553002.2019.1542182. [Epub ahead of print]

(E) (VO, IOD, IAO, DAO) Seifirad S, Farzampour S, Nourbakhsh M, Amoli MM, Razzaghy-Azar M, Larijani B Effects of extremely low frequency electromagnetic fields on paraoxonase serum activity and lipid peroxidation metabolites in rat. J Diabetes Metab Disord. 13(1):85, 2014.

(E) (VO, CE, IFR, IOD, IAO) Selaković V, Rauš Balind S, Radenović L, Prolić Z, Janać B. Age-dependent effects of ELF-MF on oxidative stress in the brain of mongolian gerbils. Cell Biochem Biophys. 66(3):513-521, 2013.

Seyhan N, Güler G. Review of in vivo static and ELF electric fields studies performed at Gazi Biophysics Department. Electromagn Biol Med. 25(4):307-323, 2006. (Review)

(E) (VO, CE, DAO) Sharifian A, Gharavi M, Pasalar P, Aminian O. Effect of extremely low frequency magnetic field on antioxidant activity in plasma and red blood cells in spot welders. Int Arch Occup Environ Health. 82(2):259-266, 2009.

(E) (VT, AE, IFR) Sherrard RM, Morellini N, Jourdan N, El-Esawi M, Arthaut LD, Niessner C, Rouyer F, Klarsfeld A, Doulazmi M, Witczak J, d'Harlingue A, Mariani J, Mclure I, Martino CF, Ahmad M. Low-intensity electromagnetic fields induce human cryptochrome to modulate intracellular reactive oxygen species. PLoS Biol. 16(10):e2006229, 2018.

(E) (VO, AE, IFR, IAO, DAO) Shine MB, Guruprasad KN, Anand A. Effect of stationary magnetic field strengths of 150 and 200 mT on reactive oxygen species production in soybean. Bioelectromagnetics. 33(5):428-437, 2012.

(E) (VO, CE, IFR, DFR, IAO, DAO) Shokrollahi S, Ghanati F, Sajedi RH, Sharifi M. Possible role of iron containing proteins in physiological responses of soybean to static magnetic field. J Plant Physiol. 226:163-171, 2018.

(E) (VT, AE, IFR) Simkó M, Droste S, Kriehuber R, Weiss DG. Stimulation of phagocytosis and free radical production in murine macrophages by 50 Hz electromagnetic fields. Eur J Cell Biol. 80(8):562-566, 2001.

Simkó M. Cell type specific redox status is responsible for diverse electromagnetic field effects. Curr Med Chem. 14(10):1141-1152, 2007. (Review)

Simkó M, Mattsson MO. Extremely low frequency electromagnetic fields as effectors of cellular responses in vitro: possible immune cell activation. J Cell Biochem. 93(1):83-92, 2004. (Review)

(E) (HU, AE, IAO, DFR) Sirmatel O, Sert C, Sirmatel F, Selek S, Yokus B. Total antioxidant capacity, total oxidant status and oxidative stress index in the men exposed to 1.5 T static magnetic field. Gen Physiol Biophys. 26(2):86-90, 2007a.

(E) (HU, AE, IFR) Sirmatel O, Sert C, Tümer C, Oztürk A, Bilgin M, Ziylan Z. Change of nitric oxide concentration in men exposed to a 1.5 T constant magnetic field. Bioelectromagnetics. 28(2):152-154, 2007b.

(E) (VT, AE, IFR) Solek P, Majchrowicz L, Bloniarz D, Krotoszynska E, Koziorowski M. Pulsed or continuous electromagnetic field induce p53/p21-mediated apoptotic signaling pathway in mouse spermatogenic cells in vitro and thus may affect male fertility. Toxicology. 382:84-92, 2017.

(E) (IV, AE, DFR) Song K, Im SH, Yoon YJ, Kim HM, Lee HJ, Park GS. A 60 Hz uniform electromagnetic field promotes human cell proliferation by decreasing intracellular reactive oxygen species levels. PLoS One. 13(7):e0199753, 2018.

(E) (VT, AE, IFR) Sullivan K, Balin AK, Allen RG. Effects of static magnetic fields on the growth of various types of human cells. Bioelectromagnetics. 32(2):140-147, 2011.

(E) (IV, AE, IFR, AO) Sun L, Chen L, Bai L, Xia Y, Yang X, Jiang W, Sun W. Reactive oxygen species mediates 50-Hz magnetic field-induced EGF receptor clustering via acid sphingomyelinase activation. Int J Radiat Biol. 94(7):678-684, 2018.

(E) (VT, AE, DFR) Sun YL, Chen ZH, Chen XH, Yin C, Li DJ, Ma XL, Zhao F, Zhang G, Shang P, Qian AR. Diamagnetic levitation promotes osteoclast differentiation from RAW264.7 cells. IEEE Trans Biomed Eng. 62(3):900-908, 2015.

(E) (VO, CE, IFR, IAO) Sun Y, Shi Z, Wang Y, Tang C, Liao Y, Yang C, Cai P. Coupling of oxidative stress responses to tricarboxylic acid cycle and prostaglandin E_2 alterations in Caenorhabditis elegans under extremely low-frequency electromagnetic field. Int J Radiat Biol. 2018 Oct 11:1-8. doi: 10.1080/09553002.2019.1524943. [Epub ahead of print]

(E) (VT, AE, IFR, AO) Tang R, Xu Y, Ma F, Ren J, Shen S, Du Y, Hou Y, Wang T. Extremely low frequency magnetic fields regulate differentiation of regulatory T cells: Potential role for ROS-mediated inhibition on AKT. Bioelectromagnetics. 37(2):89-98, 2016.

(E) (VO, CE, IX)Tasset I, Medina FJ, Jimena I, Agüera E, Gascón F, Feijóo M, Sánchez-López F, Luque E, Peña J, Drucker-Colín R, Túnez I. Neuroprotective effects of extremely low-frequency electromagnetic fields on a Huntington's disease rat model: effects on neurotrophic factors and neuronal density. Neuroscience. 209:54-63, 2012.

(E) (VO, CE, IOD, DAO) Tayefi H, Kiray A, Kiray M, Ergur BU, Bagriyanik HA, Pekcetin C, Fidan M, Ozogul C. The effects of prenatal and neonatal exposure to electromagnetic fields on infant rat myocardium. Arch Med Sci. 6(6):837-842, 2010.

(E) (VO, CE, IAO)Todorović D, Mirčić D, Ilijin L, Mrdaković M, Vlahović M, Prolić Z, Mataruga VP. Effect of magnetic fields on antioxidative defense and fitness-related traits of Baculum extradentatum (insecta, phasmatodea). Bioelectromagnetics. 33(3):265-273, 2012.

(E) (VO, CE, IAO) Todorović D, Ilijin L, Mrdaković M, Vlahović M, Filipović A, Grčić A, Perić-Mataruga V. Long - term exposure of cockroach Blaptica dubia (Insecta: Blaberidae) nymphs to magnetic fields of different characteristics: Effects on antioxidant biomarkers and nymphal gut mass. Int J Radiat Biol. 95(8):1185-1193, 2019.

(NE) (VO, CE, IX) Túnez I, Drucker-Colín R, Jimena I, Medina FJ, Muñoz Mdel C, Peña J, Montilla P. Transcranial magnetic stimulation attenuates cell loss and oxidative damage in the striatum induced in the 3-nitropropionic model of Huntington's disease. J Neurochem. 97(3):619-630, 2006.

(NE) (VO, CE) Türközer Z, Güler G, Seyhan N. Effects of exposure to 50 Hz electric field at different strengths on oxidative stress and antioxidant enzyme activities in the brain tissue of guinea pigs. Int J Radiat Biol. 84(7):581-590, 2008.

(E) (VO, AE, TFR, DFR) Van Huizen AV, Morton JM, Kinsey LJ, Von Kannon DG, Saad MA, Birkholz TR, Czajka JM, Cyrus J, Barnes FS, Beane WS. Weak magnetic fields alter stem cell-mediated growth. Sci Adv. 5(1):eaau7201, 2019.

(NE) (VT, AE) Vannoni D, Albanese A, Battisti E, Aceto E, Giglioni S, Corallo C, Carta S, Ferrata P, Fioravanti A, Giordano N. In vitro exposure of human osteoarthritic chondrocytes to ELF fields and new therapeutic application of musically modulated electromagnetic fields: biological evidence. J Biol Regul Homeost Agents. 26(1):39-49, 2012.

(E) (VO, CE, DFR, DAO) Vignola MB, Dávila S, Cremonezzi D, Simes JC, Palma JA, Campana VR. Evaluation of inflammatory biomarkers associated with oxidative stress and histological assessment of magnetic therapy on experimental myopathy in rats. Electromagn Biol Med. 31(4):320-332. 2012.

(NE) (VT, AE, IAO) Villarini M, Gambelunghe A, Giustarini D, Ambrosini MV, Fatigoni C, Rossi R, Dominici L, Levorato S, Muzi G, Piobbico D, Mariucci G. No evidence of DNA damage by co-exposure to extremely low frequency magnetic fields and aluminum on neuroblastoma cell lines. Mutat Res. 823:11-21, 2017.

Vojtísek M, Knotková J, Kasparová L, Svandová E, Markvartová V, Tůma J, Vozeh F, Patková J. Metal, EMF, and brain energy metabolism. Electromagn Biol Med. 28(2):188-193, 2009. (Review)

(E) (IV, AE, IFR, DFR) Wang D, Zhang L, Shao G, Yang S, Tao S, Fang K, Zhang X. 6-mT 0-120-Hz magnetic fields differentially affect cellular ATP levels. Environ Sci Pollut Res Int. 25(28):28237-28247, 2018.

Wang H, Zhang X. Magnetic fields and reactive oxygen species. Int J Mol Sci. 18(10), 2017, pii: E2175. doi: 10.3390/ijms18102175 Review. (Review)

Wang S, Luo J, Zhang Z, Dong D, Shen Y, Fang Y, Hu L, Liu M, Dai C, Peng S, Fang Z, Shang P. Iron and magnetic: new research direction of the ferroptosis-based cancer therapy. Am J Cancer Res. 8(10):1933-1946, 2018. (Review)

(E) (VT, AE, AO, IAO, AO) Wartenberg M, Wirtz N, Grob A, Niedermeier W, Hescheler J, Peters SC, Sauer H. Direct current electrical fields induce apoptosis in oral mucosa cancer cells by NADPH oxidase-derived reactive oxygen species. Bioelectromagnetics. 29(1):47-54, 2008.

(E) (VT, AE, IOD, IFR, AO) Wolf FI, Torsello A, Tedesco B, Fasanella S, Boninsegna A, D'Ascenzo M, Grassi C, Azzena GB, Cittadini A. 50-Hz extremely low frequency electromagnetic fields enhance cell proliferation and DNA damage: possible involvement of a redox mechanism. Biochim Biophys Acta. 1743(1-2):120-129, 2005.

(E) (VO, CE, IAO) Wu SX, Xu YQ, Di GQ, Jiang JH, Xin L, Wu TY. Influence of environmental static electric field on antioxidant enzymes activities in hepatocytes of mice. Genet Mol Res. Genet Mol Res. 15(3), 2016. doi: 10.4238/gmr.15038800.

(E) (VT, AE, IFR, AO) Yang ML, Ye ZM. [Extremely low frequency electromagnetic field induces apoptosis of osteosarcoma cells via oxidative stress]. Zhejiang Da Xue Xue Bao Yi Xue Ban. 44(3):323-328, 2015. [Article in Chinese]

(E)(VO, IV, IFR) Yang LL, Zhou Y, Tian WD, Li HJ, Kang-Chu-Li, Miao X, An GZ, Wang XW, Guo GZ, Ding GR. Electromagnetic pulse activated brain microglia via the p38 MAPK pathway. Neurotoxicology. 52:144-149, 2016.
.

(E) (VT, AE, IFR, AO)Yin C, Luo X, Duan Y, Duan W, Zhang H, He Y, Sun G, Sun X. Neuroprotective effects of lotus seedpod procyanidins on extremely low frequency electromagnetic field-induced neurotoxicity in primary cultured hippocampal neurons. Biomed Pharmacother. 82:628-639, 2016.

(E) (VO, CE, IOD) Yokus B, Cakir DU, Akdag MZ, Sert C, Mete N. Oxidative DNA damage in rats exposed to extremely low frequency electromagnetic fields. Free Radic Res. 39(3):317-323, 2005.

(E) (VO, CE, IOD) Yokus B, Akdag MZ, Dasdag S, Cakir DU, Kizil M. Extremely low frequency magnetic fields cause oxidative DNA damage in rats. Int J Radiat Biol. 84(10):789-795, 2008.

(NE) (VT, AE) Yoon HE, Lee JS, Myung SH, Lee YS. Increased γ-H2AX by exposure to a 60-Hz magnetic fields combined with ionizing radiation, but not hydrogen peroxide, in non-tumorigenic human cell lines. Int J Radiat Biol. 90(4):291-298, 2014.

(NE) (VO, AE, IX) Yoshikawa T, Tanigawa M, Tanigawa T, Imai A, Hongo H, Kondo M. Enhancement of nitric oxide generation by low frequency electromagnetic field. Pathophysiology. 7(2):131-135, 2000.

(E) (VO, AE, DAO, IOD) Zeng L, Ji X, Zhang Y, Miao X, Zou C, Lang H, Zhang J, Li Y, Wang X, Qi H, Ren D, Guo G. MnSOD expression inhibited by electromagnetic pulse radiation in the rat testis. Electromagn Biol Med. 30(4):205-218, 2011

(E) (IV, AE, CE, IFR) Zeng Y, Shen Y, Hong L, Chen Y, Shi X, Zeng Q, Yu P. Effects of single and repeated exposure to a 50-Hz 2-mT electromagnetic field on rrimary cultured hippocampal neurons. Neurosci Bull. 33(3):299-306, 2017.

(E) (HU, CE, IOD, AO) Zhang D, Zhang Y, Zhu B, Zhang H, Sun Y, Sun C. Resveratrol may reverse the effects of long-term occupational exposure to electromagnetic fields on workers of a power plant. Oncotarget. 8(29):47497-47506, 2017.

Zhang J, Ding C, Ren L, Zhou Y, Shang P. The effects of static magnetic fields on bone. Prog Biophys Mol Biol. 114(3):146-152, 2014. (Review)

(E) (VT, AE, IFR, DRF) Zhang J, Ding C, Meng X, Shang P. Nitric oxide modulates the responses of osteoclast formation to static magnetic fields. Electromagn Biol Med. 37(1):23-34, 2018.

(E) (VO, AE, IX) Zhang ZY , Zhang J , Yang CJ, Lian HY, Yu H, Huang XM, Cai P. Coupling Mechanism of Electromagnetic Field and Thermal Stress on Drosophila melanogaster. PLoS One. 11(9):e0162675, 2016.

(E) (VT, AE, IFR) Zhao G, Chen S, Wang L, Zhao Y, Wang J, Wang X, Zhang W, Wu R, Wu L, Wu Y, Xu A. Cellular ATP content was decreased by a homogeneous 8.5 T static magnetic field exposure: role of reactive oxygen species. Bioelectromagnetics. 32(2):94-101, 2011.

(E) (VT, AE, IX, LI) Zmyslony M, Rajkowska E, Mamrot P, Politanski P, Jajte J. The effect of weak 50 Hz magnetic fields on the number of free oxygen radicals in rat lymphocytes in vitro. Bioelectromagnetics. 25(8):607-612, 2004a.

(E) (VT, AE, IX, LI) Zmyślony M, Palus J, Dziubałtowska E, Politański P, Mamrot P, Rajkowska E, Kameduła M. Effects of in vitro exposure to power frequency magnetic fields on UV-induced DNA damage of rat lymphocytes. Bioelectromagnetics. 25(7):560-562, 2004b.

(E) (VT, AE, IOD, IAO) Zwirska-Korczala K, Adamczyk-Sowa M, Polaniak R, Sowa P, Birkner E, Drzazga Z, Brzozowski T, Konturek SJ. Influence of extremely-low-frequency magnetic field on antioxidative melatonin properties in AT478 murine squamous cell carcinoma culture. Biol Trace Elem Res. 102(1-3):227-243, 2004.