SUPPLEMENTARY MATERIAL

Literature on free radical generation after exposure 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) ↓ protein carboxylation in					

		prenatal (Pr), postnatal (Po, 30 days), and prenatal + postnatal (PP)	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 hippocampal	1-Hz MF, 0.56 and 0.056 mT, 10 min			Effect blocked by NOS			60-Hz MF has no significant

	slices				inhibitor			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	Restraint	Static MF, 0.8						Attenuated

-Urrutia et al. (2018)	Wistar rats	mT, 30, 60, 240 min/day, 5 days						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 al. (2003)	Bovine articular cartilage explants	75-Hz EMF 1.3 ms pulses, 2.3 mT peak, 24 h		Ø NO				Pulses enhanced Interleukin-1β–induced NO production
De Nicola et	U937 cells	Static MF, 6 mT, 2 h; 50-		↑ ROS		↓GSH		Decreased apoptosis

al. (2006)		Hz MF, 0.07-0.1 mT, 2 h						
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 Wistar rat in vivo, liver	50-Hz MF, 1 mT, 4/day, 45 days	Ø lipid peroxidation					Increased 3-nitrotyrosine (oxidative/ nitrosative stress) in liver of female rats.
Errico	NB4 cells	50 Hz MF, 2		↑ROS				

Provenzano et al. (2018)	(human acute promyelocytic leukemia)	mT, 8, 16, 24 h						
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	50-HZ MF, 0.1, 0.2, or 0.4 mT, 5, 15, 30,		↑ ROS				↑ total ROS at 0.2 mT and higher,

	cells	or 60 min						↑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 rate of change in MF 3.3 T/s) 24 or 48 h	MF ↑DNA methylation with 24 h exposure (not with 48 h)					Oxidative stre (300 μM H_2O_2) decreased DNA methylation compared to PMF alone
Glinka et al.	Male Sprague-	40-Hz MF, 10 mT, 30 min	↓ lipid peroxidation in liver of 6-day exposure			↑SOD-Mn in serum only in 6 day exposure, ↓SOD-Mn in liver in 14-		↑glutathione s-

(2013)	Dawley rat in vivo, blood serum and liver	/day for 6, 10, or 14 days				day exposure. No effect on SOD-ZnCu ↑ GPx in serum in 10- and 14-day exposure		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				↓SOD		↑Total antioxidant capacity, faster growth of seedlings, decrease

		(22 µT), 5 h/day for 4 days						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 neuroblastoma cells	50-Hz MF, 0.1 mT, 24 h		↑ cytosolic $O_2^{\cdot-}$ production; ↓ mitochondrial $O_2^{\cdot-}$ production				
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	60-Hz MF,1 mT, 4 or 16 h						MF did not affect H_2O_2-induced DNA strand breaks.

	L132, and human mammary epithelial MCF10A cells								
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	Human	60-Hz MF, 22		↑ $O_2^{\cdot-}$					

al. (1999)	neutrophils simulated by phorbol 12-myristate13-acetate	mT, 10 min						
Kim et al. (2017)	RAW 264.7 macrophage	60-Hz MF, 0.8 mT, up to 20 h		↑NO				Decreased effectivenes s 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/apy rimidinic sites (DNA lesion)
Kthiri et al. (2019)	Saccharomy ces	Static magnetic field,	↑ lipid peroxidation and protein carboxylation			↑ SOD and CAT ↓GP_X after 9 h exposure		Decrease in growth after

	cerevisiae (yeast)	250 mT, 6 and 9 h						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 Trolox and a nitric oxide synthase inhibitor.	Effects blocked by the iron 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 monocyte and human mono Mac 6 cells	50-Hz MF, 1 mT, 45 min		↑ total ROS, ↑ $O_2^{\cdot-}$				Mono Mac 6 cells more sensitive, 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					MF-induced MAPK-p38 and ERK1/2 activation blocked by	

		for 15-120 min					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 induced 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 $O_2^{\bullet -}$ ↑ 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 vertical 50-Hz 30 μT MF, 2 h		↑ cytosolic $O_2^{\bullet -}$ in vertical static field plus horizontal 50-Hz MF (but not vertical 50-Hz MF); Mtochondrial $O_2^{\bullet -}$ not affected				Cell viability not affected.
*Nakayama 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.	Human erythro-	50-Hz MF, 1 mT, 24 h			↓ iNOS reaction	↑ CAT activity		

(2015)	leukemic K562 cell				velocity			
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, digestive gland	50-Hz MF, 0.5, 2.5,10 and 50 μT, 10 days in lab; 2.88 and 0.75 μT for 10, 20, 40, 60 days in field	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 Lab: Ø GSH, ↓ Glutathione reductase Field: ↓ glutathione reductase		Total oxyl-radical scavenger capacity: 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.	Human breast	100 and 217 Hz pulsed		↑ ROS in 217 Hz 72-h, not in 100 Hz exposure				

(2012)	carcinoma cell (T47D)	EMF, 0.1 mT, 24-72 h						
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	↑ $O_2^{\bullet -}$ ↑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		↑ $O_2^{\bullet -}$, 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		↑ $O_2^{\bullet -}$				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-		↑ $O_2^{\bullet -}$ ↑ NO				Cell cycle arrest and apoptosis observed

		wave EMF, 2.5-8 mT, 2 h						
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 dithiocarbamate	Increase in free radicals correlated to clustering of 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	Ø DNA oxidative damage Ø lipid peroxidation			Ø GSH ↓ GSSG		MF reversed 3-nitropropionic acid induced oxidative stress.

		head)						
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 h in the afternoon for 4 days (applied to the head)						MF itself had no effect on different 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 8 days after exposure		↓NO		↓SOD		Pulsed EMF caused muscle recovery.
*Villarini et al. (2017)	SH-SY5Y 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.	HL-60	50-Hz EMF,	↑ DNA oxidative damage	↑ ROS in Rat-1 fibroblast			Effect	Dose-

(2005)	leukemia cells, Rat-1 fibroblast, WI-38 diploid fibroblast	0.5-1 mT, 24-72 h					blocked by alpha-tocopherol.	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 hippocampal neurons	50-Hz MF, 8 mT, 90 min	↑ lipid peroxidation	↑ ROS		↓SOD		
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.	Male BALB/C	60-Hz MF, 0.1 mT, 5.5 h						MF did not induce NO

(2000)	mouse injected with lipopolysaccharide (LPS) in vivo, liver							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.)					

<u>Literature list</u> (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)

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