Static/ELF EMF-Gene expression (May 31, 2026)

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(References can be found in the 'static-ELF EMF-genetic effects' file)

*** no significant effect observed. Studies showed 'effect' =232 (92%), 'no effect'= 20 (8%)**

	Exposure conditions	Results	Gene functions
Abdel Rahman et al. (2025)	Rats exposed to 50 Hz EMF; 3 h/day for 30 days (no flux density provided).	Increase p53 and Bax gene expression, decreased BCl2 expression in tongue and parotid gland.	Tumor protein p53 conserves stability by preventing genome mutation and prevents cancer development. It is often mutated in human cancer. Bax is a pro-apoptosis protein that affects the voltage-gated anion channels on mitochondrial membrane. BCL2 blocks apoptosis.
Abdelhaliem et al. (2023)	Leaves of corn *(Zea mays)* seedlings exposed to 60-Hz, 10 mT EMF for 1, 3, or 5 days.	Changes in patterns of gene expression and increased DNA strand breaks.	Genes not specified.
Agliassa et al. (2018)	*Arabidopsis thaliana* (thale cress) exposed to 0.00004 mT static magnetic field for 38 days after sowing (hypomagnetic field).	Changes in gene expression in leaf and floral meristem (cryptochrome-related gene involved); delayed flowering time and a significant reduction of leaf area index and flowering stem length, with respect to controls under geomagnetic field.	Cryptochromes are flavoproteins found in plants and animals that are sensitive to blue light. They are involved in the circadian rhythms and the sensing of magnetic fields.
Ahmadi-Zeidabadi et al. (2019)	Human glioblastoma U87 cells exposed to 100-Hz 10 mT MF for 120-144 h.	Increased expression of Nestin, CD133, Notch4, and GFAP genes, synergistic with temozolomide. Oxidative processes involved.	Nestin- filament proteins expressed mostly in nerve cells where they and implicated in the radial growth of the axon. CD133- a member of transmembrane glycoproteins, an organizer of cell membrane topology. Notch4- plays a role in a variety of developmental processes by controlling cell fate decisions. GFAP- filament (IF) protein that is expressed by numerous cell types of the central nervous system,

			involved in the structure and function of the cell's cytoskeleton.
Akbarnejad et al. (2017)	Human U87 and T98G glioma cells exposed to 100-Hz 10 mT MF for 144 h.	Increased gene expression of p53, Bax, caspase-3, and oxygenase-1, and decreasing that of Bcl-2 and Cyclin-D1. Oxidative processes involved.	Tumor protein p53 conserves stability by preventing genome mutation. Bax is a pro-apoptosis protein. Caspase-3 is related to apoptotic processes. Bcl2 blocks apoptosis. Cyclin D1 is related to cell cycle progression.
Albaqami et al. (2020)	*Arabidopsis* (rockcress) seedlings exposed to 0.0002 mT static MF; 3 h under blue light activation.	Increased expression of cryptochrome-regulated genes (IAA, PIN1, and PIN3).	Cryptochromes are flavoproteins found in plants and animals that are sensitive to blue light. They are involved in the circadian rhythms and the sensing of magnetic fields.
Ashta et al. (2020)	Human glioblastoma cells (A172) exposed to 10 Hz or static magnetic field at 5 mT, up to 96 h.	Increased p53 gene expression, cytotoxicity and free radical formation; effects enhanced by Temozolomide.	Tumor protein p53 conserves stability by preventing genome mutation and prevents cancer development.
Attia et al. (2024)	Human laryngeal carcinoma Hep-2 ell incubated with Polyvinyl alcohol-capped silver nanostructures (cAgNSs) and exposed to 50-Hz MF at 50 mT for 15 min.	Increased p53 and BECN-1, and decreased NF-κB gene expressions.	Tumor protein p53 conserves stability by preventing genome mutation. BECN-1 involves in autophagy and cell death. NF-κB-controls DNA transcription, cytokine production and cell survival.
Asci et al. (2026)	Penile, testicular, prostatic, and renal tissues of rats exposed to 27.12 MHz RFR (10 V/m) and 1 Hz EMF (0.5 mT) for 30. 60, or 90 min/day for one day, I week, or 1 month	Increased nitric oxide synthase (eNOS) and decreased tumor necrosis factor-alpha (TNF-α) mRNA expression; no effect on vascular endothelial growth factor (VEGF) mRNA	Endothelial NOS (eNOS) produces NO in the vascular endothelium plays crucial roles in regulating vascular tone, cellular proliferation, leukocyte adhesion, and platelet aggregation. TNF-α is a chemical messenger produced by the immune system, primarily by activated macrophages, that induces inflammation.

Bahari et al. (2025)	DU-145 prostate cancer cells exposed to 50 Hz pulsed EMF (pulse characteristic not defined) at 22.6 or 35 mT for 30 min.	Dose-dependent increases in expression of the tumor suppressor gene PTEN and the apoptosis-inducing gene BAX; reduced the expression of the oncogene MIR-21 and, the BCL-2 gene, which blocks apoptosis.	
Bai et al. (2021)	Neural stem cells exposed to 50-Hz 5 mT EMF 30 min/day for 3 days.	Increased expression of Tuj-1 gene.	Tuj-1 gene accelerates stem cell differentiation into neurons.
Balcer-Kubiczek et al. (1996)	HL-60 cells exposed to 60 Hz EMF, 24 h at 0.2 mT.	No effect on expression of c-myc, β-actin, c-fos, ornithine decarboxylase, Glyceraldehyde-3-Phosphate Dehydrogenase, and ribosomal genes.	
Balcer-Kubiczek et al. (1998)	HL-60 cells exposed to 60 Hz EMF, 3 h at 2 mT.	No effect on expression of genes related to cell growth, protein synthesis, energy metabolism, oxidative stress or apoptosis.	
Balci et al. (2025)	Kidney of rats with acute kidney injury caused by lipopolysaccharide (LPS) exposed to 1 second MF square-wave pulses (inter-pulse duration 1 sec) at 0.5 mT for 30 min.	MF pulses reversed effects of LPS on gene expression of IL-6, HIF-1α, eNOS, Bcl-2, and Cas9.	IL-6 is secreted by macrophages in response to specific microbial molecules. IL-6 is an important mediator of fever and of the acute phase response, in the production of neutrophils in the bone marrow and supports the growth of B cells and is antagonistic to regulatory T cells. The transcription factor HIF-1 plays an important role in cellular response to systemic oxygen levels in mammals. eNOS is involved in nitric oxide synthesis. Bcl-2 blocks apoptosis. Cas9 plays a vital role in the immunological defense of certain bacteria against DNA viruses and plasmids. Its

			main function is to cut DNA and thereby alter a cell's genome.
Bertea et al. (2015)	*Arabidopsis thaliana* (thale cress) exposed to artificially reversed geomagnetic field. conditions for 10 days at .0419 mT.	Significant effects on plant growth and gene expression observed. This supports the hypothesis that GMF reversal contributes to inducing changes in plant development that might justify a higher selective pressure, eventually leading to plant evolution.	
Betlej et al. (2026)	Gynecological (HeLa, ES-2) and urological (DU-145) cancer cells exposed to 50 Hz EMF for 15 or 30 min at 1.3 mT.	ES-2 cells showed upregulation of *XRCC5* gene expression. No effect on H2AFX, OGG1, XRCC6, POLβ, and MAP1LC3B genes. No effect on HeLa cell genes.	XRCC5 encodes ATP-dependent DNA helicase II or DNA repair protein XRCC5. XRCC% acts with XRcc4 in repair of double strand DNA breaks.
Bindal et al. (2026)	Brain of rats treated with lipopolysaccharide (LPS) to induce neuroinflammation exposed to 27.12 MHz field at 10v/m for 0.5 h and/or 1 Hz, 0.5 mT 50% duty cycle monophasic square wave for 3 h.	EMF attenuated LPS-induced changes in gene expression of P13K, AKT, HIF-1α, eNOS, and VEGF.	The P13K gene refers to the phosphoinositide 3-kinase (PI3K) delta (PIK3CD) gene, which encodes a key enzyme in the PI3K signaling pathway. PI3Ks are lipid kinases that phosphorylate phosphoinositides, generating second messengers like phosphatidylinositol (3,4,5)-trisphosphate (PIP3), which regulate cell growth, survival, metabolism, and immune function. Akt1 is a mediator of growth factor-induced neuronal survival and inhibitor of apoptosis. HIF-1α is the master transcriptional regulator of cellular and developmental response to hypoxia. Its dysregulation and overexpression have been heavily implicated in cancer biology(vascularization, angiogenesis, energy metabolism, cell survival, and tumor invasion.) Endothelial NOS (eNOS) produces NO

			in the vascular endothelium plays crucial roles in regulating vascular tone, cellular proliferation, leukocyte adhesion, and platelet aggregation. VEGF acts on endothelial cells and increased vascular permeability, inducing angiogenesis, vasculogenesis, and endothelial cell growth, promoting cell migration, and inhibiting apoptosis.
Campbell-Beachler et al, (1998)	Pheochromocytoma PC12 cells treated with nerve growth factor, forskolin, and tetradecanoylphorbol acetate exposed to MF of 12.5, 25, 50, or 100 μT for 30 min.	Increased c-fos transcripts	The c-Fos gene encodes a protein that functions as a transcription factor, playing a crucial role in cellular processes such as proliferation, differentiation, and response to external stimuli.
Chang et al. (2004)	Neonatal mouse calvarial bone cells exposed to a pulsed EMF (15 Hz, 0.1 mT) for 14 days.	Increased osteoprotegerin (OPG) mRNA expression and decreased the receptor activator of NF-kappaB ligand (RANKL) mRNA expression.	Osteoprotegerin (OPG) is a cytokine receptor of the tumor necrosis factor (TNF) receptor superfamily, having a role in tumor growth and metastasis, immune system development and signaling, and the prevention of osteoporosis during pregnancy. Nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) is a family of transcription factor protein complexes. It controls transcription of DNA, cytokine production and cell survival. Incorrect regulation of NF-κB has been linked to cancer, inflammatory and autoimmune diseases.
Chen GD et al. (2008)	Human MCF-7 breast cancer cells exposed to a 50-Hz magnetic fields for 24 h at 0.4 mT.	Identified three 50-Hz MF responsive genes in MCF-7 cells.	
Chan J. et al. (2020)	Human choriocarcinoma cells exposed to DC electric field (150 mV/mm) for 8 h.	Increased gene expressions of ErbB and HIF-1 signaling pathways.	ErbB and HIF-1 are involved in cell migration/motility, cell cycle progression and proliferation.

Chen, S. et al. (2025)	Rats exposed to a 50 HZ EMF at 30 mT for 14 days (4 /day).	Decreased IL-1β and TNF-α gene expression in spleen cells (probably involved the NF-κB signaling pathway). Reduced apoptosis observed.	IL-1β and TNF-α have strong proinflammatory effects.
Chen Y et al. (2021)	Human mesenchymal stem/stromal cells exposed to pulsed EMF (51.8 and 52.3 Hz); 6-0.282 mT, 7 or 30 min.	Increased expression of *COL1A1*, *FN1*, and *BGN* genes depending on waveform and frequency.	COL1A1, FN1, and BGN are involved in extracellular matrix.
Cheng L et al. (2022)	*Caenorhabditis elegans* exposed to 0.67 T static MF or 50-Hz 0.7 mT MF; 30 min every10 h for a total of 300 min.	Affected expression of serotonin-related genes.	Serotonin is a neurotransmitter.
Cheng Y et al. (2017)	Human umbilical vein endothelial cells exposed to 50-Hz 2.25 mT pulsed EMF for 15 min.	Increased expression of mTOR gene.	The mammalian target of rapamycin (mTOR) regulates cell growth, cell proliferation, cell motility, cell survival, protein synthesis, autophagy, and transcription.
Choi et al. (2025)	LPS-activated RAW264.7 macrophages exposed to 60-Hz EMF at 0.5 mT for 7 days	Increased expression of iNOS. TNF-α, IL-6, IL-1 β genes	iNOS-- nitric oxide syntheses; TGF-β -- immune and stem cell regulation; IL-6-- immune responses;
Cichoń et al. (2018)	Human patients after stroke; 40-Hz, 5 mT EMF (rectangular bipolar waveform); ten 15-min sessions.	Increased gene expression of brain-derived neurotrophic factor. (level measured in blood).	
Cichoń et al. (2019)	Human patients after stroke; 40-Hz, 5 mT EMF (rectangular	Increased expression of interleukin 1β mRNA	IL-1β has strong proinflammatory effects.

	bipolar waveform); ten 15-min sessions.		
Cichoń et al. (2020)	Human patients after stroke; 40-Hz, 5 mT EMF (rectangular bipolar waveform); ten 15-min sessions.	Increased apoptotic gene expressions (*BAX*, *CASP8*, *TNFα*, and *TP53)*	
Ciombor et al. (2002)	Model of demineralized bone matrix (DBM)-induced bone formation in implanted rats; 4.5 ms pulses, 15 pulses/second 1.6 mT EMF, ,75 Hz; 8 h/day for 6-8 days.	Increased expression of PG and type II collagen mRNA	Type II collagen in cartilage plays a role in joint health and structure integrity.
Cios et al. (2024)	Clear cell renal cell carcinoma cells (clear cell renal cell carcinoma) and healthy HEK293 cells exposed to 50 Hz MF at 4.5 mT ; 30 min/day for 5 days.	Changes in expression of *ADAM28*, *NCAM1*, and *VEGFC* genes; response is cell type dependent	Genes are involved in cell-cell and cell-matrix interactions, cell-cell adhesion, and growth of blood vessels and their permeability.
Colciago et al. (2021)	Human vestibular schwannoma HEI-193 cells exposed to 50-Hz 0.1 T MF for 10 min or 10 min/day for 5 days.	Hearing loss-related genes (NEFL, TPRN, OTOGL, GJB2, and REST) deregulated in chronic exposed cells.	
Colciago et al. (2024)	Rat transformation Schwann cells exposed to 50 Hz MF at 0.1 T for 10 min.	Decreased DNA methylation, affected expression of genes related to developmental, immunological, metabolic and stress-activated	

		processes; upregulated gene expression related to hypoxic and oxidative stress in mitochondria (decreased mitochondrial membrane potential).	
Collard et al. (2013)	Epidermis cultures harvested from human abdominoplasty exposed to ELF electric fields (a biphasic, asymmetric, charge-balanced current stimuli, with a repetition frequency of 4 0 Hz modulated by a fundamental frequency of 0.125 Hz. The exposure was repeated during 4 s followed by a 4 s break for 40 min/day for 11 days.	Observed a significant change in genes expression after 4 days and change in expression in another group of genes at day 4 and 7.	Genes are involved in cell proliferation or differentiation, mitosis, cell cycle or in DNA replication transcription and translation.
Consales et al. (2018)	Human SH-SY5Y neuroblastoma cells and mouse primary cortical neurons exposed to a 50-Hz magnetic field at 1 mT for 4-72 h	Expressions of microRNA miR-34b/c that caused mitochondrial oxidative stress, also altered α-synuclein expression involved in synaptic functions. These effects may be related to neurodegeneration.	
Consales et al. (2022)	Neuroblastoma SH-SY5Y cells exposed to 50 Hz, 1 mT EMF for 24 h.	Increased *egr-1* and *c-fos* gene expression	EGR-1 gene encodes a nuclear protein and functions as a transcriptional regulator. The target genes are required for differentiation, mitogenesis, neuronal plasticity, and memory formation. The c-Fos gene encodes a protein that functions as a transcription factor, playing a crucial role in cellular processes such as proliferation,

			differentiation, and response to external stimuli. transcription factor, playing a crucial role in cellular processes such as proliferation, differentiation, and response to external stimuli.
Coskun et al. (2021)	Rat pain -model; 10 or 30 Hz pulsed MF 1.5 mT, 1 h/day for 4 weeks.	Changes in expression of gene related to voltage-gated sodium channels in dorsal root ganglion tissue	
Costantini et al. (2019)	Human gingival fibroblast model for wound healing; 1 mT sinusoidal (50 Hz) or pulsed (0.3 ms, 12 Hz) EMF for 6 or 18 h.	Increased in an early expression of IL-6, TGF-β, and iNOS genes and a later induction of MMP-2, MCP-1, and HO-1 genes	IL-6-- immune responses. TGF-β -- immune and stem cell regulation. iNOS-- nitric oxide syntheses. MMP-2 -- tissue repair, wound healing, and angiogenesis. MCP-1 -- inflammation. HO-1 – heme catabolism.
*Coulton et al. (2004)	Human blood exposed to 50 Hz EMF; 0-100 μT, 4 h.	No detectable effect on expression of the genes encoding HSP27, HSP70A, and HSP70B.	
Cuccurazzu et al. (2010)	Mice exposed to 50 Hz EMF at 1 mT for 1-7 h/day for 7 days.	Induced increases in the transcription of pro-neuronal genes (Mash1, NeuroD2, Hes1) and genes encoding Ca(v)1.2 channel α(1C) subunits in the hippocampus. Generation of new granule cells in the dentate gyrus.	
Czerska et al. (1992)	Daudi lymphoma cells exposed to 60 Hz MF at 0.25 – 1 mT for 15, 30, or 60 min.	Increased c-myc gene expression at 1 mT after 60 minexpsoure (Longer exposure duration for 3, 6, or 12 h produced no effect).	
Czyz et al. (2004)	p53-deficient mouse pluripotent embryonic	Up-regulation of c-jun, p21 and egr-1 genes. No	The c-jun gene encodes a transcription factor that regulates gene expression and is involved in cell proliferation, differentiation, apoptosis, and cancer

	stem cells exposed to 50 Hz EMF 5 min ON/30 min OFF, 2.3 mT for 6 h.	effect at lower flux densities, longer exposure time or after 18 h recovery time. No effect on wild type stem cells.	development. P21 regulates cell cycle and responses to DNA damage. egr-1 gene encodes a nuclear protein and functions as a transcriptional regulator.
Daou et al. (2024)	Human mesenchymal stem cells exposed to PEMF (1.5 mT, 75 Hz); 4 hr/day for 21 days.	Slight increase in expression of collagen type-1 alpha 1 (osteogenesis) and collagen type-2 alpha 1(chondrogenesis) genes. Changes in expression of 11 other genes also observed.	
de Girolamo et al. (2013)	Human tendon cells exposed to PEMF (1.5 mT peak; 1.3 ms pulse duration, 75 Hz, duty cycle 0.1) for 4, 8, or 12 h.	Increased expression of VEGF-A gene	Vascular endothelial growth factor-A (VEGF-A) is a signal protein acts on endothelial cells and has various effects, including mediating increased vascular permeability, inducing angiogenesis, vasculogenesis, and endothelial cell growth, promoting cell migration, and inhibiting apoptosis.
Dehghani-Soltani et al (2021)	Temozolomide-treated T98 and A172 cells exposed to 50-Hz 7 mT EMF.	overexpression of the p53 gene and downregulation of cyclin-D1 protein.	p53 has a role in conserving stability by preventing genome mutation.
de Kleijn et al. (2016)	Hypothalamic paraventricular nucleus, pituitary, and adrenal glands from mice exposed to 20-500 Hz 0.01 mT EMF 1, 4, or 24 h/day for 1 or 15 weeks.	Decreased proopiomelanocortin (POMC) gene expression; hypothalamic-pituitary-adrenal axis affected.	Proopiomelanocortin is a precursor protein produced by the pituitary, It is cleaved in α-MSH, ACTH, and β-endorphin.
De Mattei et al. (2005)	MG-63 human osteoblast-like cell exposed to pulsed EMF (1.3 ms, 75 Hz,	Increased then decreased with longer exposure in c-myc and c-fos gene expression (involved in cell differentiation)	

	1:10 duty cycle, 2.3 mT) for 0.5-24 h.		
Di et al. (2021)	Mice exposed to static electric field (56.3 kV/m) 24h/day for 28 days.	Decreased mRNA of testicular StAR, PBR, CYP11A1 (involved the mitochondria and free radicals)	These are genes encoding enzymes involved in synthesis of steroids and steroid hormones particularly in the inner membrane of the mitochondria.
Di Campli et al. (2010)	*Helicobacter pylori* biofilm exposed to 50-Hz EMF at 1 mT for 2 days.	No changes in DNA patterns were recorded, whereas a modulation in amiA gene expression was detected; phenotypic changes induced.	amiA protein is involved in septum formation during cell division.
Dong D et al. (2019)	Human pre-osteoclast RAW264.7 cells exposed to a 16 T static magnetic field for 2-4 days.	HiSMF markedly blocked the expression of osteoclast-associated transcription factors and osteoclast marker genes and inhibited iron absorption and iron storage-related protein expression. Mitochondrial concentration and oxidative stress levels in osteoclasts were decreased under magnetic field exposure.	
Dong L et al. (2022)	Mice exposed to static electric field of 56.3 kV/m for 21 days.	Increased mRNA expression levels of tumor necrosis factor-α (TNF-α) and nuclear factor-κB (NF-κB) in the spleen; related to increase in free radicals	NF-κB is a transcription factor that regulates immune responses, inflammation, cell proliferation, and survival. TNF-α is a chemical messenger produced by the immune system that induces inflammation.
Dong Y et al. (2021)	Mouse MC3T3-E1 cells (can differentiate into osteoblasts and osteocytes) coated with piezoelectric	Increased expression of late osteogenic genes.	

	scaffold (a property of bone) exposed to 50 Hz pulsed EMF (0.6 mT) .		
Drzewiecka et al. (2021)	Myometrium of pigs exposed to 50 Hz 8 mT EMF for 2 h.	Increased expression of genes involved in defense and immune responses	
Erdal ME et al. (2018)	Mice (3- or 10-weeks old) exposed to 50 Hz 1 mT EMF; 4 h/day for 60 days.	Age-dependent Increase or decrease in miRNA expression in blood and brain	
Fan et al. (2015)	Rat bone marrow derived-mesenchymal stem cells exposed to a 50-Hz EMF at 1 mT for 4 h/day for 3 days.	Increased cell viability, DNA synthesis and proportion of cells in S phase and up-regulate the expression of hematopoietic growth factors genes.	
Fan et al. (2018)	*Enterococcus faecalis* (isolated from dental infection) exposed to a static magnetic field at 170 mT for 24 or 72 h.	Static magnetic field up regulates the expression of stress gene (dnaK) and virulence genes (efaA and ace). Synergistic with alkaline pH induced by calcium hydroxide (a major dental antimicrobial) in antimicrobial action and up-regulation of stress and virulence genes.	
Fang et al. (2024)	Rat bone marrow mesenchymal stem cells exposed to 15 Hz sinusoidal EMF at 0.6-1 mT, 4 h/day for 7-14 days.	miR-34b-5p downregulated (inhibition of miR-34b-5p promote osteogenic differentiation of BMSCs) (EMF could be an effective treatment of osteoporosis)	

Fathi and Farahzadi (2017)	Rat adipose tissue-derived mesenchymal stem cells exposed to 50 Hz 20 mT EMF with Zn SO_4.	Increased mRNA expressions of β-catenin, Wnt1, Wnt3a, LRP5 and DKK1; induced oeteogenic differentiation of the stem cells	These genes are involved in cell adhesion, tissue and embryonic development particularly in the Wnt signaling pathway.
Fedrowitz and Loscher (2012)	Female F344 and Lewis rats exposed to a 50-Hz magnetic field at 0.1 mT 24 h/day for two weeks.	F344 breast tissue showed alterations in gene expression, which were absent in Lewis rats, particularly, α-amylase, a stress marker.	
Felaco et al. (1999)	Human peripheral blood mononuclear cells exposed to 50 Hz EMF at 1,5 mT for 24, 48, or 72 h.	Increased CD4+ mRNA only at 24 h of exposure. CD4+ gene encodes a glycoprotein that plays a role in the immune system particularly in T-lymphocyte activation.	CD4+ is involved in signaling in immune responses activation of T-helper cells.
Franczak et al. (2020)	Procine myometrial slices exposed to 50 or 120 Hz EMF for 2 or 4 h.	Altered CYP17A1 mRNA transcript abundance after 4 h exposure.	CYP17A1 is involved in steroid hormone synthesis, e.g., glucocorticoids.
Franczak et al. (2022)	Porcine conceptuses during the peri-implantation period (days 15-16 of pregnancy) exposed to 50 and 120 Hz EMF for 2 or 4 h.	Decreased CYP19A3 mRNA transcript in conceptuses treated with progesterone	CYP19A3 gene encodes aromatase-enzyme for estrogen synthesis.
Franczak et al. (2023)	Porcine myometrium during the peri-implantation period exposed to 50Hz EMF, 8 mT EMF for 2 h.	Increased the level of genomic DNA methylation (epigenetic mechanisms)	

Franczak et al. (2025)	Pig conceptuses during peri-implantation period exposed to 50 Hz EMF, 8 mT, 2 h.	Increased DNA methylation levels and affected the expression of genes involved mainly in cellular homeostasis, conceptuses development, and attachment.	
Frisch et al. (2013)	Transfected rat primary fibroblast (RAT1) cells exposed to 10 Hz electric fields at 20-500 V/m for 2 h.	Induced HSP70 heat shock gene expression, with peak responses obtained at 8 h following exposure.	Hsp70 proteins can protect cells from thermal or oxidative stress. These stresses normally act to damage proteins, causing partial unfolding and possible aggregation.
Gholamian-Hamadan et al. (2023)	Rats exposed to 50 Hz EMF; 2 h/day for 60 days at 0.001, 0.1, 0.5 and 2 mT (with the immune system activated by human serum albumin) .	Expression of gene of activation-induced deaminase decreased by 0.0001 mT exposure.	The gene encodes a DNA-editing deaminase involved in somatic hypermutation, gene conversion, and class-switch recombination of immunoglobulin genes in B cells of the immune system.
*Goh et al. (2025)	HeLa and B103 cells exposed to 60 Hz MF 10-16 mT for 72 h.	No effect on gene expression. (Decreased cell proliferation observed.)	
Goodman and Shirley-Henderson (1991)	HL-60 and dipteran salivary gland cells exposed to pulsed or CW ELF EMF at different frequencies and intensity for 20 min.	Increased transcription of actin, histone H2B, and v-myc genes. Frequency-, field strength and time-dependent “windows” are observed	
Goodman et al. (1983)	Salivary glands of *Sciara coprophila*; repetitive pulse trains (15 Hz) or repetitive single pulse EMF for 15 or 45 min.	Increased RNA; effect depended on wave form.	

Goodman et al. (1992a)	*Drosophila melanogaster* salivary gland exposed to 1.5-72 Hz MF at 0.35-3.5 mT for 20 min.	Change in RNA transcription in chromosome 3R (oncogene and genes involved in development)	
Goodman et al. (1992b)	HL-60 cells exposed to 60-Hz EMF; 0.57-570 μT for 10. 20, or 40 min.	An increase in the basal levels of these normally expressed transcripts (c-my, β-actin, c-src, β-tubulin, and histone H2B) is observed with dependence on both field strength and time of exposure. Window effect observed at 5.7 μT for 20 min.	
Goodman et al. (1994)	HL-60 and yeast cells exposed to 60- Hz EMF at 0.8-80 μT for 20 min.	Increased hsp-70 transcripts.	Hsp70 proteins can protect cells from thermal or oxidative stress. These stresses normally act to damage proteins, causing partial unfolding and possible aggregation.
Gulla et al. (2026)	Human glioblastoma cells (U-87) exposed to a sequence of EMF fields (10 Hz to 10 KHz; 10 - 400 μT) that lasted 55 min; once a day for 4 days	Decreased expression of stemness-related genes (POU5F1 and NANOG); increased expression of pro-apoptosis genes (BCL2L11 and BBC-1); increased expression of mesenchymal-associated genes: CDH1 (E-cadherin) and no effect on CD44 and ALDH1A3 genes.	
Guo et al. (2023)	Zebrafish larvae exposed to 50 Hz MF at 100-800 μT for 1 or 24 h for 5 days.	Increased expression of the neurodevelopment-related gene syn2a. Attenuated by ROS scavenger.	Syn2a is involved in synaptic organization.
Han et al. (2018)	Human MCF-7 breast cancer cells and MCF10A normal breast cells exposed to	Promoted DNA synthesis in MCF-7 cells affected cell cycle. EMF increased mRNA of cell cycle-	

	50 Hz 1 mT EMF for 2-12 h, with 5-fluorouracil.	related proteins Cyclin D1 and Cyclin E.	
Harrison et al. (1997)	MCF7 WT, HeLa S3, and A172 cells exposed to 60 Hz magnetic field at 2 mT for 24 h (assayed at various times after exposure).	No effect on *c-myc, c-fos, β-actin*, glyceraldehyde-3-phosphate dehydrogenase (*GAPDH*) gene transcripts.	
He et al. (2018)	Human bone marrow macrophages exposed to pulsed EMF (from a commercial machine).	Upregulation of genes of mesenchymal or osteoblastic cells, included members of the TGF-β signaling pathway and many extracellular matrix proteins,	
Heidari et al. (2021)	Human adenocarcinoma gastric cancer cells exposed to 0.2 and 2 mT 50-Hz EMF continuously and discontinuously (1.5 h on/1.5 h off) for 18 h.	Decreased expression of B-cell lymphoma 2 gene, and increased expression of miR-15-b and miR-16	B-cell lymphoma 2 promotes cellular survival and inhibiting the actions of pro-apoptotic proteins.
Heredia-Rojas et al. (2010)	Human non-small cell lung cancer cells (INER-37) and mouse lymphoma cells (RMA E7) (transfected with a plasmid with hsp70 expression when exposed to magnetic field and contains the reporter for the luciferases gene) exposed to a 60-Hz magnetic field at	An increase in luciferase gene expression was observed in INER-37 cells exposed to magnetic field, but similar exposure had no effect on the RMA E7 cell line.	

	0.008 and 0.00008 mT for 20 min.		
Hirai et al. (2006)	Hippocampal neurons from embryonic rats exposed to static MF at 100 mT for 15 min.	Increased transcription of Ntan1 gene leading to MAP2 (microtubule-associated protein 2) protein degradation through ubiquitin-proteasome pathway.	MAP2 stabilizes microtubule protein.
*Huang et al. (2023)	AML12 and HEK293 cells exposed to increasing frequency EMF 1-8 Hz in 8 sec of 4 msec pulses at 10 μT for 3 h.	No effect on HSP80 and HSP90 gene expression. (Decreased protein expression and increased acetylation of HSP80 and HSP90, and enhanced protein folding.)	
Hwang et al. (2023)	Immortalized mouse myoblast C2C12 cells transfected with electromagnetic perceptive gene and exposed to 196 mT static magnetic field for 12 or 48 h.	Decreased gene expressions of Glucose transporter type 4 (GLUT4) and peroxisome proliferator-activated receptors (PPARg2), leading to decreased triglyceride synthesis via a calcium-dependent reaction.	
Jahreis et al. (1998)	CEM-CM3 cells exposed to a 60-Hz EMF at 0.1 mT for 15, 30, 60, or 120 min.	No effect on expression of c-fos, c-jun, and c-myc oncogenes	
Jedrzejczak-Silicka et al. (2021)	Fibroblast L929 and HaCaT cells exposed to rotating MF of different frequencies (30 and 50 Hz) and intensities (up to 28.4 mT) for 4 h.	Exposure parameter-dependent up and down regulations of genes (including wound healing genes) (free radicals and calcium involved)	

Jeong et al. (2021)	Human glioblastoma cells (U373) exposed to 'tumor-treating field' (120 kHz, 1.2 V/cm electric field) .	Decreased DNA damage and gene expression levels of BRCA1, PCNA, CDC25C, and MAD2	BRCA1 is involved in DNA repair and mutation can lead to certain cancers. PCNA gene encodes the Proliferating Cell Nuclear Antigen, a crucial protein involved in DNA replication and repair processes in eukaryotic cells. PCNA gene is involved in the regulation of cell division. The MAD2 gene encodes a crucial protein involved in the spindle checkpoint, which ensures proper chromosome segregation during cell division.
Jin Y et al. (2019)	*Arabidopsis* young seedlings exposed to a static magnetic field at 600 mT.	Increased auxin (a plant growth hormone) from expression of PIN3 and AUX1 genes in root tips; cryptochromes (cry1 and cry 2) are also involved. Root growth enhanced. Effects occurred when static magnetic field was parallel and perpendicular not opposite, to geomagnetic field.	
Junkersdorf et al. (2000)	*Caenorhabditis elegans* exposed to 50 Hz MF at 0.1 mT for 60-180 min.	Increased expression of lacZ reporter gene in heat stressed (30ºC) worms. (No data on non-stress worms)	
Kaneda et al. (2025)	Sympathetic neuron-like PC12 cells exposed to 171-411 mT static MF for 18 h.	37 genes affected including genes of GABAB receptor pathway—and the circadian entrainment pathway were activated.	
Karimi et al. (2022)	Human endogenous retroviruses in human skin malignant melanoma SK-MEL-37 cells exposed to 50-Hz EMF at 1.5 and 3 mT for 96 hours.	Downregulated HERV gene expression	HERV-gene is associated with complex diseases particularly, neurodegenerative and psychiatric disorders.

Karoubi et al. (2024)	Human dermal transgenic fibroblast cells, they were transfected by Plenti3-hsa-miR451, Plenti3-hsa-miR16 and Plenti3-backbone inserted into *E. coli* Stbl4 genome, 10 mT static MF, 20 min/day for 7 days.	Increased expression of hematopoiesis-related genes (*α-chain*, *β-chain*, *γ-chain* and *GATA1* genes); enhanced cell differentiation into erythroid like progenitors	
Kazemi et al. (2018)	Male rhesus macaques exposed to1 or 12 Hz 0.0007 mT EMF 4h/day for 30 days.	Increased NMDA receptor gene expression with 12-Hz exposure (enhanced visual working memory function)	NMDA is a neurotransmitter.
Kazemi et al. (2022a)	Male rhesus macaques exposed to 12 Hz 0.0007 mT EMF 4h/day for 30 days.	Increased NMDA receptor gene expression (enhanced visual working memory function; increased plasma adrenocorticotropic hormone)	
Kazemi et al. (2022b)	Male rhesus macaques exposed to 12 Hz 0.0007 mT EMF 4h/day for 30 days.	Decreased expression of lymphocyte glucocorticoid gene (Decreased plasma cortisol)	
Ki et al. (2020)	Human hair follicle dermal papilla cells, a type of cells involved in hair growth, exposed to a 70 Hz EMF at intensities	Increased the expression of anagen-related molecules, including collagen IV, laminin, ALP, and versican, and increased β-catenin and Wnt3α expression and GSK-3β/ERK/Akt	Anagen is the first phase of hair growth.

	ranging from 0.5 to 10 mT over four days.	phosphorylation. Cell proliferation enhanced.	
Kim J. et al (2026)	Brain of rats exposed to 60 Hz (cycles of 16.67 ms) consisting of 20 unipolar pulses per cycle at 2 mT, with complex exposure schedules up to 60 days	Caused gene switch mediated by cytochrome b5b: genes involved in reversing aging phenotypes, conditional expression of human mutant amyloid precursor protein, and restore serotonergic function.	
Kimsa-Dudek et al. (2018)	Normal human dermal fibroblasts exposed to static magnetic field at 0.65 T for 24 h and sodium fluoride.	Static magnetic field attenuated expression of antioxidant defense genes (SOD1, PLK3, CLN8, XPA, HAO1) induced by sodium fluoride.	
Kimsa-Dudek et al. (2020)	Normal human dermal fibroblasts exposed to static magnetic field at 0.45, 0.55 and 0.5 T for 24 h and sodium fluoride.	The field reduced fluoride-induced apoptosis and affected apoptosis gene expression; reduced fluoride-induced increases in reactive oxygen species and lipid peroxidation and decrease in antioxidant enzymes.	
Kimsa-Dudek et al. (2022)	Human skin malignant melanoma C32 cells treated with phenolic acid and exposed to 0.7 T Static MF for 24 h.	Static MF interacted with phenolic acid affected expression of apoptosis (Bax, BC12 and BclX1) and Caspase 3 and 9 genes.	
Kimura et al. (2008)	*Caenorhabditis elegans* exposed to 2, 3, or 5 T static	Genes involved in motor activity, actin binding, cell adhesion, and cuticles are transiently and	

	magnetic field for 4-24 h.	specifically induced; also hsp (heat shock protein) 12 and 16 family genes.	
Kitaoka et al. (2013)	Mice exposed to 60-Hz 1.5 mT EMF for 200 h.	Reduction in Cyp17a1 mRNA (adrenal corticosteroid synthesis enzymes); animals showed depression-like behavior	
Klimiuk et al. (2026)	Hippocampus of rats exposed to 50 Hz EMF at 1 or 7 mT for three 7-day periods (1 h/day) with 3-wek break between cycles.	1 mT exposure increased and 7 mT exposure decreased pro-neuroplastic factors gene expression. (Genes related to neurogenesis (BDNF, TrkB, GAP43), synaptic activity (PSD95, SYN1), and cell survival (Bcl-2, Bcl-xL, Bak1 were studies.)	
Kobayashi-Sun et al. (2024)	Zebrafish scale exposed to 60-Hz EMF for 24 h at 10 mT.	Upregulated *wnt10b* and Wnt target genes and facilitated osteoblast and osteoclast activities. No effect at 3 or 30 mT.	Wnt gene family encodes proteins involved in oncogenesis and developmental regulation. Wnt10B is implicated in breast cancer and affects adipogenesis.
Kostyn et al. (2023)	Flax seedlings exposed to 50 Hz EMF at 0.5 mT for 30 min.	Increased expressions of different genes including those involved in stress and ROS processing.	
Kozlowska et al. (2021)	Pig endometrium exposed to 50 Hz 8 mT EMF for 2 h.	Affected 1561 transcriptionally active regions in the genome including genes encoding proteins that are involved in proliferation and	

		metabolism in endometrial tissue.	
Kwiatkowski et al. (2022)	*Staphylococcus aureus* FRI913 strain exposed to 5 or 50 Hz rotating magnetic field for 12 h.	50 Hz increased *agrA* and *sea* transcripts (regulatory genes)	AgrA is a transcription regulator on expression of virulence factors that enable bacteria to invade host tissues. SEA gene codes enterotoxin production in Staphylococcus aureus.
*Lacy-Hulbert et al. (1995)	Human leukemic cells (HL60) exposed to a 60-Hz EMF for 20 min at 0.00057, 0.0057, or 0.057 mT.	No change in MYC and beta-actin gene expression observed.	
Lai, Y et al. (2022)	Hippocampus of rats exposed to EMF (400 V/m, 5 ns rise time, 500 ns width, 1 Hz, 400 pulses total).	Overexpression of prostaglandin-endoperoxide synthase 2 (PTGS2) mRNA. (Gene involved in the conversion of arachidonic acid to prostaglandin H_2, an important precursor of prostacyclin, which is expressed in inflammation.) (Ferroptosis observed.)	
Laramee et al. (2014)	Transfected rat primary fibroblast (RAT1) cells exposed to static magnetic fields of 1 to 440 mT for 16, 24, or 48 h starting at 24 and 48 h post transfection.	Induction of heat shock protein (HSP70) expression showed a dependency on flux density, exposure duration, and start time post transfection.	
Lazzarini et al. (2023)	Human breast cancer MDA-MB-231 and normal MCF-10A	Up-regulated genes enriched in "focal adhesion" and	

	breast cells exposed to 50 Hz 1 mT EMF for 4 h.	"mitochondrion" in both cell lines; transcription factors associated with cellular reprogramming were upregulated in MDA-MB-231 cells and downregulated in MCF-10A cells. (Involved free radicals)	
Lee C-H et al. (2010)	*Caenorhabditis elegans* exposed to exposed to a static magnetic field at 200 mT.	Expression of genes involved in development and aging. Accelerated development and shorten lifespan.	
Lee HC et al. (2016)	MCF10A, MCF7, Jurkat, and NIH3T3 cells exposed to a 60 Hz magnetic field at 1 mT for 4 or 16 h.	MCF10A and MCF7 cells showed consistent and significant decreases in cell number, cell viability, and DNA synthesis rates (cell cycle delay), whereas Jurkat and NIH3T3 cells showed no effect. MCF7 cells (2 mT for 16 h) showed up-regulation of PMAIP1 gene (involved in apoptosis).	
Leone et al. (2014)	Neural stem cells isolated from hippocampi of newborn mice exposed to a 50-Hz EMF at 1 mT for 10 days.	Histone acetylation-related chromatin remodeling leading to enhanced proliferation and neuronal differentiation.	
Li SS et al. (2013)	Male *Drosophila melanogaster* fruit flies exposed to a 50-	Different sets of genes were up- and down-regulated after short- or long-term exposure.	

	HZ EMF at 3 mT for 72 or 312 h.	Short-term exposure may decrease the reproductive ability of males, whereas long-term exposures had no effect on reproductive ability.	
Li Y. et al. (2014)	Fertilized embryos of zebra fish (*Danio rerio*) exposed to a 50-Hz magnetic field at 0.1 - 0.8 mT for 96 h.	The transcription of apoptosis-related genes (caspase-3, caspase-9) was significantly up-regulated in exposed embryos. Delayed hatching and apoptosis observed.	
Li, Y. et al. (2015)	Rat oligodendrocyte precursor cells exposed to DC electric field at 50, 100. Or 200 mV/mm for 1.5 h.	Mitogen-activated protein kinase pathway that signals cell migration was significantly upregulated in cells treated with an EF of 200 mV/mm compared with control cells and downregulation of differentially expressed genes in chemotaxis.	
Li Y. et al. (2019)	Dementia rats induced by streptozotocin (STZ) intracerebroventricular injection exposed to a 10 mT 20-Hz pulsed EMF, 2 h/day, 10 days.	Pulsed EMF increased expression of insulin growth factor 2 (IFG-2) gene in the hippocampus and improved the ability of learning and memory in STZ-treated rats.	IFG-2 is a polypeptide growth factor involved in cell proliferation and differentiation, and growth, especially during fetal development.
Li Y. et al. (2022)	Honeybee (*Apis cerana*) larvae exposed to 50Hz 3 mT EMF from second day	Altered expression of 422 genes, with six genes related to energy production and nutrient uptake and utilization downregulated (decreased	

	of life to end of development.	survival rate and extended development time)	
Liao et al. (2025)	L929 mouse fibroblasts exposed to pulse 80 Hz EMF (burst width 2 ms, pulse width 10.5 ms) peak 4 mT 30 min per day for two days.	Upregulated expression of antioxidant and glycolysis related genes. (Increased cell acidity and shifted to glycolysis)	
Liburdy et al. (1993)	Activated rat thymic lymphocytes (by Con-A) exposed to 60-Hz MF at 22 mT for 60 min.	Increased c-myc mRNA	The c-myc gene is a crucial proto-oncogene that encodes a transcription factor involved in regulating cell growth, proliferation, and apoptosis, and is often implicated in various cancers.
Lin H et al. (1998)	Plasmid exposed to 60 Hz EMF at 0.008 mT for 30 min.	Induction of HSP70 gene expression by c-myc protein	
Lin et al. (1999)	Plasmid exposed to 60 Hz EMF at 0.008 mT for 30 min'.	Induction of HSP70 gene expression by c-myc protein on three binding sites. Heat shock element gene involved.	
Lin KW et al. (2016)	Budding yeast exposed to a 50-Hz EMF at 6 mT for 96 h.	The transcription levels of 28 genes were upregulated and those of four genes were downregulated. Exposure can upregulate the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not the glycolysis pathway.	

Lin Y. et al. (2025)	Brain of mouse exposed to 80 ns, 10 Hz EMP at 6000 Kv/m, 1000 pulses/day for 14 days.	Increased mRNA of IL-6, IL-1β, iNOS, and TNF-α	IL-6-- immune responses, IL-1β–inflammation and immune responses, TGF–β -- immune and stem cell regulation. iNOS-- nitric oxide syntheses.
Liu C et al. (2023)	Zebrafish embryos exposed to 11.4 T magnetic field from 6-24 hours post fertilization.	up-regulation of tumor necrosis factor genes	tumor necrosis factor genes encodes a pro-inflammation cytokine, and regulates cell proliferation, differentiation, apoptosis, lipid metabolism, and coagulation.
Liu J. et al. (2024)	Rat model of Osteoporotic osteoarthritis exposed to PEMF (3.82 mT, 8 Hz; (burst width, 25 ms; burst wait, 100 ms; pulse width, 0.2 ms; pulse wait, 0.05 ms) 40 min/day, 5 day/week for 12 weeks.	PEMF attenuated Osteoporotic osteoarthritis-induced increases in Beclin-1, P62, and LC3B mRNA expression (involved in regulation of autophagy and cell death) in bone marrow of femurs and tibias.	
Liu Y et al. (2015b)	Mouse spermatocyte-derived GC-2 ells exposed to 50-Hz EMF for 72 h (5 min on/10 min off) at 1, 2, or 3 mT.	Up- and down-regulation of 15 miRNA depending on field intensity (These miRNAs may regulate circadian rhythms, cytokine-cytokine receptor interactions and the p53 signaling pathway).	
Liu Y et al. (2016)	Mouse spermatocyte-derived GC-2 ells exposed to 50-Hz EMF for 72 h (5 min on/10 min off) at 1, 2, or 3 mT.	Increased expression of Cyckin D2 (CCND2) gene and miR-26b-5p	Cyckin D2 gene encodes cylin D2 protein that is involved in cell cycle.

Loberg et al. (1999)	Human breast epithelial cells exposed to linearly polarized 60 Hz EMF at 0.01, 0.1, or 1 mT for 20 min, 60 min, 4 h, or 24 h.	No effect on expression of c-myc, c-erbB-2, p53, p21, GADD45, bax, bcl-x, mcl-1, and c-fos genes.	
Loberg et al. (2000)	Normal (HME) and transformed (HBL-100) human mammary epithelial cells and human promyelocytic leukemia (HL60) cells exposed to 60 Hz MF at 0.01 or 1 mT for 2 h.	No effect on 588 cancer-related genes.	
Lu et al. (2024)	rat bone marrow-derived mesenchymal stem cells (BMSCs) exposed to 20. 40. 60, 80, or 100 Hz EMF at 1 mT for 24 h.	Increased expression of osteogenic marker genes (Runx2, BSP, Bglap and Osx)- frequency-dependent up to 80 Hz. (Frequency-dependent increase in proliferation observed up to 80 Hz. !00 Hz caused a decrease in proliferation.) (Gene expression was not studied at 100 Hz).	
Lupke et al (2006)	Human umbilical cord blood-derived monocytes exposed to a 50-Hz magnetic field at 1 mT for 45 min.	Alteration of 986 genes involved in metabolism, cellular physiological processes, signal transduction and immune response.	
Ma et al. (2014)	Mouse embryonic neural stem cells exposed to a 50-Hz	Expression of genes regulating neuronal	

	EMF at 2 mT for 3 days.	differentiation was altered.	
Ma et al. (2016)	Embryonic neural stem cells exposed to 50-Hz 1 mT EMF for 4 h/day for 1, 2, or 3 days.	Up-regulated the expression of transient receptor potential canonical 1 and proneural genes (NeuroD and Ngn1) (gene responsible for neuronal differentiation and neurite outgrowth, which were observed after EMF exposure)	
Mahaki et al. (2019)	Rats exposed to a 50-Hz EMF at 0.001-2 mT for 2 h/day for 60 days.	In the spleen, gene expression levels of RORα (retinoid-related orphan receptor alpha) and c-Maf (transcription factor Maf) were significantly down-regulated at 0.001 and 0.1 mT, while the expression of STAT6 (signal transducer and activator of transcription 6) was only significantly decreased at the density of 0.1 mT. No effect on thymus.	RAR-related orphan receptor alpha (RORα) participates in the transcriptional regulation of some genes involved in circadian rhythm, development of cerebellum and plays an essential role in the development of type 2 innate lymphoid cells. c-Maf controls immune responses by suppressing IL-2 in CD4+ T-cells. STAT6 (Signal transducer and activator of transcription 6) gene encodes a protein involved in diseases including hyper-Ige Syndrome 6, autosomal dominant, With recurrent infections and hemangiopericytoma.
Mahdavinejad et al. (2018)	Spleen Th17 and regulatory T (Treg) cells of rats exposed to 50 Hz EMF at 0.001, 0.1, 0.5 and 2 mT for 2 h/day for 2 months.	Expression of transcription factor forkhead box P3 (Foxp3) was downregulated at intensities of 0.001 and 0.1 mT	Foxp3 regulates the functions of regulatory T-cell, that turns the immune responses that destroy cancer cells.

Mahmoudinasab and Saadat (2016a)	Human MCF-7 cells exposed to a 50-Hz magnetic field at 0.25 and 0.5 mT (5 min ON/5 min OFF, 15 min ON/15 min OFF, or 30 min field-on continuously) for 30 min.	Alterations in the *NQO1* and *NQO2* (NAD(P)H: quinone oxidoreductase) mRNA levels seen at the "5 min ON/5 min OFF" condition.	NAD (P)H:quinone oxidoreductase (NQO) is an antioxidant flavoprotein that catalyzes the reduction of highly reactive quinone metabolites by employing NAD (P)H as an electron donor.
Mahmoudinasab and Saadat (2016b)	Human MCF-7 cells exposed to 50 Hz 0.25 or 0.5 mT EMF (5 min field-on/5 min-off; 15 min field-on/15 min field-off; or continuous field) for total exposure time of 30 min.	Up and down regulations of the antioxidant genes (*CAT*, *SOD1*, *SOD2*, *GSTO1*, *GSTM3*, *MSGT1*, and *MSGT3*) depending on exposure pattern and intensity.	
Mahmoudinasab et al. (2016c)	Human MCF-7 cells exposed to a 50-Hz magnetic field at 0.25 and 0.5 mT (5 min ON/5 min OFF, 15 min ON/15 min OFF, or 30 min field-on continuously) for 30 min.	Significant changes in mRNA levels of seven antioxidant genes for "the 15 min field-on/15 min field-off condition".	
Mahmoudinasab and Saadat (2018a)	MCF-7 and SH-SY5Y cells exposed to 50-Hz EMF at 0.5 mT (15 min ON/ 15 min OFF) and treated with morphine and cisplatin.	EMF exposure could protect SH-SY5Y cells from the cytotoxicity of cisplatin and morphine, whereas there is no significant change in MCF-7 cells. Expression patterns of antioxidant genes are different in both cell lines.	

Mahmoudinasab and Saadat (2018b)	SH-SY5Y cells exposed to 50-Hz EMF at 0.5 mT (“15 min ON/ 15 min OFF” and “30 min ON”) for 30 min, and treated with morphine and beta-lapachone.	NQO1 mRNA level decreased in the "15 min field-on/15 min field-off" condition, the expression level of NQO2 was increased. Morphine and EMF reduced the cytotoxicity of beta-lapachone.	The NQO1 gene encodes an enzyme that plays a crucial role in detoxifying quinones and protecting cells from oxidative stress, with implications for various diseases, including cancer and neurodegenerative disorders.
Mansoury et al. (2020)	Human gastric adenocarcinoma cell line (AGS) exposed to 50 Hz EMF; 0.25-2 mT (continuous or 2h on/2 h off) for 18 h.	On/off exposure- decreased myc gene expression (more at 0.25 and 0.5 mT than at 1, or 2 mT); similar pattern for circ-ccd66 gene expression. Continuous exposure- myc gene expression decreased at 0.25 mT and increased at 1 and 2 mT; decreased circ-ccd66 gene expression- more at 0.25 mT than at 1 and 2 mT.	Circ-ccd66 gene is a circular RNA that has been identified as an oncogenic circRNA. It is up regulated in various malignant tumors. It regulates cancer progress.
Mansoury et al. (2021)	Human gastric adenocarcinoma cell line (AGS) and human normal fibroblast (Hu02) cells exposed to 50-Hz EMF of 0.25, 0.5, 1, or 2 mT for 18 h (1 h ON/1 h OFF).	Downregulation of NOTCH1 and its regulatory circular RNA (circ-RNA) in cancer cells and upregulated in normal cells.	The Notch1 gene encodes a protein known as Neurogenic locus notch homolog protein 1, which is involved in the Notch signaling pathway, which plays a role in cell fate determination, growth, differentiation, and apoptosis.
Mansoury et al. (2022)	Human gastric adenocarcinoma cell line (AGS) and human normal fibroblast (Hu02) cells exposed to 50-Hz EMF of 0.25, 0.5	Decreased rapamycin (mTOR) and hsa_circ_100338 in cancer cells at 0.25 and 0.5 mT. mTOR and hsa_circ_100338 are involved in cell growth,	

	,1, or 2 mT for 18 h continuously.	proliferation, differentiation, and metastasis). mTOR expression increased in normal cells.	
Manzella et al. (2015)	Human dermal fibroblasts exposed to a 50 Hz magnetic field at 0.1 mT for 1 h.	Changes in expression of clock genes.	Clock genes regulate circadian rhythms, and influence sleep, metabolism, and hormone secretion.
Marmotti et al. (2026)	Human tendon tissue exposed to PEMF (pulse duration 1.3 ms, 75 Hz, duty cycle 0.3, peak 1.5 mT); 8 h/day for 21 days	Increased mRNA (mRNA) levels of scleraxis, collagen type I, collagen type VI, and mammalian target of rapamycin (mTOR); no effect on mRNA levels c-fos, proliferating cell nuclear antigen (PCNA), and β-catenin.	These proteins are tendon-related markers (scleraxis, collagen types I and VI) and important players of tenogenic differentiation (c-Fos and mammalian target of rapamycin).
Martinez et al. (2022)	Human NB69 neuroblastoma cells exposed to 50 Hz 0.1 mT MF for 30 or 120 min.	Increased p53 gene expression	p53 protein acts as a guardian of the genome. It regulates cell division and prevents the formation of tumors.
Martini et al. (2020)	Human mesenchymal stem cells exposed to pulsed 75 Hz 1.5 mT EMF in combination with bone morphogenetic protein-2 (BMP2) for 28 days.	Increased BMP2, BMP6, and BMP type I receptor gene expression, involved in mesenchymal stem cells osteogenic differentiation.	BMP-2 protein has been demonstrated to potently induce osteoblast differentiation, and involved in the development of bone and cartilage. BMP-6 is involved in the development of bone and cartilage. BMP type I receptor binds members of the TGF beta superfamily of ligands—the bone morphogenetic proteins.
Mastrodonato et al. (2018)	Mice exposed to a 50 Hz, 1 mT EMF 3.5 h/day for 12 days.	Increased Wnt3 (neurogenesis gene) mRNA expression and nuclear localization of its downstream target β-	

		catenin in subventricular zone of the lateral ventricle. Mice showed enhanced olfactory memory at 30 days post-exposure.	
*Mayer-Wagner et al. (2018)	human mesenchymal stem cells exposed to 15 Hz 5 mT EMF for 3 weeks.	No effect on COLXA1 and COL2A1 gene expression. MF interacts with simulated microgravity on expression of these gene.	The COLXA1 gene is associated with the expression of stromal Type X collagen, which plays a role in the tumor microenvironment of breast cancer. The COL2A1 gene encodes the alpha-1 chain of type II collagen, essential for the structure and function of cartilage and connective tissues.
Mehdizadeh et al. (2023)	Uman glioblastoma U87 and U251 cells exposed to 1 Hz 100 mT EMF, 2 h/day for 5 days.	Gene expression levels of P53, P21, and MDM2 were increased and CCNB1 was decreased in U87, MCM6 expression decreased in U251. (Changes may be related to apoptosis induced by the field.)	p53 protein acts as a guardian of the genome. It regulates cell division and prevents the formation of tumors. P21 regulates cell cycle and responses to DNA damage. MDM2 gene encodes a protein that is a negative regulator of p53 tumor suppressor. CCNB1 encodes Cyclin B1, a regulatory protein involved in the control of cell cycle, particularly during mitosis. CM6 gene encodes a protein essential for DNA replication.
Mendoza-Mari et al. (2025)	Human microglial cells (HCM3) and cortical neuron cells ((NCN2) treated with TNF-α to induce inflammation exposed to 2.5 or 5 Hz EMF for 3 min (no flux density provided).	2.5 Hz- decreased IL-1β gene expression; 5 Hz- decreased NF-κβ and CASP1 gene expression.	Genes related to inflammation.
Miladi et al. (2026)	HCT116 colorectal cancer cells exposed to 50 Hz Emf for 9 or 18 h, at 0.4 or 0.8 mT, continuously or	Downregulation of expression of miR-138, miR-135, and miR-21, and upregulation of miR-141.	miR-138 is involved in different molecular pathways and is in relation with various types of cancer. miR135 regulates adenomatosis polyposis coli gene that negatively regulates cell adhesion molecules and may be involved in colorectal cancer MicroRNA-21 is a highly conserved small

	intermittently (30 min on/30 min off)		noncoding RNA that plays a central role in regulating gene expression across a broad range of biological processes, including development, immune response, and cellular homeostasis. miR-141 acts as a suppressor or an oncomiR in various cancers and regulates cancer cell proliferation, apoptosis, invasion, and metastasis.
*Miller et al. (1999)	Human promonocytic U937 leukemia cells exposed to 60 Hz EMF of 0.08, 0.1, 1.0 or 1.3 mT.	No effect on NF-kappaB or AP-1-dependent reporter gene expression	The Nuclear factor kappa B (NF-κB) transcription factors are key regulators of gene expression culminating in response to stress and the development of innate and acquired immunity. Activator protein 1 (AP-1) is a transcription factor that regulates gene expression in response to a variety of stimuli, including cytokines, growth factors, stress, and bacterial and viral infections.
Miller et al. (2016)	Human annulus fibrosus (AF) and nucleus pulposus (NP) cells exposed to pulsed EMF (15 Hz burst frequency square wave), 4 h/day for 7 days; cells were exposed to interleukin 1α (IL-1α) to stimulate the inflammatory environment.	EMF reduced IL-1α-associated gene expression of IL-6 in NP cells and MMP13 in AF cells	Interleukin 6 (IL-6) is an interleukin that acts as both a pro-inflammatory cytokine and an anti-inflammatory myokine. MMP13 gene encodes collagenase 3, Which is involved in the degradation of extracellular matrix proteins, including collagen.
Miyakawa et al. (2001)	Transgenic *Caenorhabditis elegans* exposed to 60 Hz 0.5 T EMF.	Expression of the hsp-16-lacZ gene was enhanced.	Gene in C. elegans, that encodes a family of stress-inducible proteins in response to heat shock and various chemical stressors.
Mohamed et al. (2022)	Human MCF-7 breast cancer cells exposed to 1 mT ELF-EMF for 1 or 2 h.	Up-regulation in the expression of p53, iNOS and NF-kB genes, and down-regulation of Bcl-2 and miRNA-125b genes	p53 protein acts as a guardian of the genome. It regulates cell division and prevents the formation of tumors. iNOS -nitric oxide syntheses. Nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) is a family of transcription factor protein complexes that controls transcription of DNA, cytokine production and cell survival.

			Bcl-2 blocks apoptosis. MiR-125 family members are involved in cell differentiation, proliferation and apoptosis as a result of targeting messenger RNAs related to these cellular processes.
Mohamed et al. (2026)	Human Schwann cells exposed to 50 Hz EMF at 0.1 T, 10 min/day for 5 days	Upregulation of genes related to mitochondrial dynamics, such as ATP5MF-PTCD1, and promoting cell migration, tumorigenesis and tumoral invasion. Changes in mitochondrial functions may be related to hearing loss.	
Molina-Montenegro et al. (2023)	Honeybees exposed to ELF EMF at 7.8 μT for 5 min.	Enhanced expression of heat-shock proteins and genes involved in antioxidant activity and affected the expression levels of behavior-related genes.	
Monirul Islam et al. (2020)	*Arabidopsis thaliana* exposed to near null magnetic field (30 nT) .	Genes involved in lipid metabolism affected.	
Moori et al. (2024)	Human breast cancer (MDA-MB 231) and normal breast (MCF1A) cells exposed to 1 Hz EMF at 100 mT, 2 h/day for 5 days.	Increased E-cadherin, decreased N-cadherin mRNA in MDA-MB 231 cells, increased E-cadherin mRNA in MCF1A cells. (Reduced migration and invasion of MDA-MB 231 cells.)	Cadherins ("calcium-dependent adhesion") are cell adhesion molecules important in forming adherens junctions that let cells adhere to each other. In epithelial cell cancers, disrupted cell-cell adhesion might lead to metastases resulting from abnormalities in the expression of E-cadherin. E-cadherin-epithelial cadherin; N-cadherin- neural cadherin.
Moraveji et al. (2016)	Dermal papilla mesenchymal cells exposed to 50-Hz EMF at 1 mT for 5-14 days	Increased expression of MAP gene with decreased cell proliferation (cell differentiation occurred.) (MAP2 protein involves	

		in neuritogenesis to stabilize microtubules.)	
Morehouse et al. (2000)	Daudi cells exposed to 60-Hz EMF at 12.5, 50, 100, or 500 μT for 20, 40, or 60 min.	No effect on c-myc RNA content.	
Mouhoub et al. (2017)	*Salmonella hadar* grown under static magnetic field of 200 mT for 3, 6, or 9 h.	Increased expression of gene involved in the production of acdiolipin and phosphatidylethanolamine (both components of bacteria cell membrane).	
Mustafa et al. (2021)	Murine FDC-P1 hematopoietic cells exposed 50 Hz 0.2 mT MF for 15 min, 2 h, 12 h, or 24 h.	Circadian rhythm-related genes were upregulated after 12 h of MF exposure and downregulated after 24 h of MF exposure.	
Mustafa et al. (2022)	Human SH-SY5Y neuroblastoma cells exposed to 0.1 mT 50-Hz or 60-Hz MF for 24 h.	A general low-magnitude increase in the expression of reactive oxygen species-related genes	
Nam et al, (2025)	Mice with lipopolysaccharide (LPS)-induced osteoporosis exposed to pulsed EMF (4 KHz bursts of 5 μs at 40 Hz), 10 mT for 17 days.	In blood and spleen-decreased interferon-γ and increased interleukin-10 gene expression-resulting in an anti-inflammation response.	Interferon-γ, or type II interferon, is a cytokine that is critical for innate and adaptive immunity against viral,some bacterial and protozoan infections. IL-10 is a cytokine with multiple effects in immunoregulation and inflammation. It downregulates the expression of Th1 cytokines, MHC class II antigens, and co-stimulatory molecules on macrophages. It also enhances B cell survival, proliferation, and antibody production.

Nasrabadi et al. (2018)	Neonatal human retinal pigment epithelial cells exposed to pulsed 50-Hz EMF at 1 mT for 8 h daily for 3 days.	Both gene and protein expressions of retinal progenitor cell markers were reduced.	
Nikolova et al. (2005)	Mouse embryonic stem (ES) cells exposed to an intermittent (5 min ON/30 min OFF) 50-Hz EMF at 2 mT for 6 or 48 h.	Significantly affected transcript levels of the apoptosis-related bcl-2, bax, and cell cycle regulatory "growth arrest DNA damage inducible" GADD45 genes, No effect on DNA single and double strand breaks.	
Oladnabi et al. (2019)	Retinal pigment epithelial cells exposed to 50 Hz 1 mT pulsed (20 ms pulses) EMF for 8 h/day for 3 days.	Transcript levels of proangiogenic genes (HIF-1α, VEGFA, VEGFR-2, CTGF, cathepsin D, TIMP-1, E2F3, MMP-2, and MMP-9) increased significantly.	
Owen (1998)	HL-60 cells exposed to 60-H EMF at 0.006 mT for 20 min.	No effect on expression of MYC gene.	
Ozturk et al. (2022)	Rat dams exposed to 50-Hz 0.5 mT EMF 24h/day during the gestational and lactational period, offspring studied.	Exposure in the prenatal and postnatal period upregulates IL-17 gene expression in the spleen, resulting in $CD4^+$ cell proliferation and inflammation.	The IL-17 gene encodes a proinflammation cytokine that plays a role in immune responses and inflammation.
Park et al. (2022)	Human bone marrow mesenchymal stem cells exposed to 30. 45, 60, or 75 HZ MF	Increased expression of several neural development genes at 60 and 75 Hz	

	at 10 mT, 30 min/day for 3 days.		
Patruno et al. (2015)	HaCaT keratinocytes exposed to 50 Hz 1 mT EMF for 1 or 24 h.	EMF exposure modulated distinct patterns of gene expression involved in cell proliferation and cell cycle (mTOR).	
Paul et al. (2006)	Transgenic Arabidopsis plant exposed to SMF at 15 T for 2.5 h.	Induction of stress-related genes and transcription factors, and a depression of genes associated with cell wall metabolism.	
Peng et al. (2020)	Myocardial infarction mice exposed to 15 Hz 1.5 mT pulsed EMF or 30 Hz 3.0 mT pulsed EMF for 45 min/ day for 2 weeks.	Increased the mRNA level of VEGF and hypoxia inducible factor 1-alpha (HIF-1α) in the infarct border zone. (Heart functions improved).	Vascular endothelial growth factor (VEGF) is a signal protein produced by many cells that stimulates the formation of blood vessels. HIF1A is considered as the master transcriptional regulator of cellular and developmental response to hypoxia. The dysregulation and overexpression of HIF1A by either hypoxia or genetic alternations have been heavily implicated in cancer biology.
Pesqueira et al. (2017)	Human tendon-derived cells exposed to a 2 Hz magnetic field at 350 mT for 4 or 8 h, or 8 h every 24 or 48 h up to 14 days.	8-h exposure significantly upregulated the expression of tendon-associated genes SCX, COL1A1, TNC and DCN. 8 h every 24 h exposure significantly upregulated collagen-related proteins COL1A1, COL3A1 and TNC on day 14.	
Phillips et al. (1992)	CEM-CM3 T-lymphoblastoid cells exposed for 15-120 min to a 60-Hz sinusoidal MF at 0.1 mT.	Time-dependent and cell density-dependent changes in the transcription of c-fos, c-jun, c-myc and protein kinase C (beta-form) genes.	The cFos gene encodes a protein that functions as a transcription factor, playing a crucial role in cellular processes such as proliferation, differentiation, and response to external stimuli. transcription factor, playing a crucial role in cellular processes such as proliferation, differentiation, and response to external stimuli. The c-jun gene encodes a transcription factor that regulates gene expression and is involved in cell

			proliferation, differentiation, apoptosis, and cancer development. The c-myc gene is a crucial proto-oncogene that encodes a transcription factor involved in regulating cell growth, proliferation, and apoptosis, and is often implicated in various cancers. Protein kinase C (beta-form) is involved in cellular signaling and regulates cell growth, differentiation, and apoptosis. It is activated by calcium ion.
Piszczek et al. (2022)	Human monocytic macrophage Mono Mac 6 (MM6) cells exposed to 7 Hz 30 mT EMF or 3 h. (Cells were phagocytosing.)	Upregulate mRNA encoding iNOS (nitric oxide synthase)	
Porcher et al. (2024)	*Arabidopsis thaliana* plants exposed to 30,000 EM pulses (237 kV/m, 280 ps rise-time, duration of 500 ps).	No effect on expression of genes involved in calcium metabolism, signal transduction, ROS, and energy status. (Ascorbate peroxidases APX-1 and APX-6 were significantly induced 3 h after the exposure).	
Potenza et al. (2004a)	*E. coli* XL-1Blue exposed to static magnetic field at 300 mT up to 50 h.	Increased cell proliferation and changes in gene expression observed. The field magnetic field may stimulate transposition activity.	
Rahimi e al. (2023)	Human mesenchymal stem cells derived from dental pulp multipotent stromal stem cells exposed to 50 Hz EMF at 0.5 or 1	Increased expression of dentin matrix acidic phosphoprotein 1 (involved in proper mineralization of bone and dentin) gene in differentiating cells.	

	mT for 20 or 40 min/day for 7 days.		
Rai et al. (2024a)	Brain of mini-swine traumatic brain injury model; 2.5 Hz and 3.5 Hz 1V sinusoidal EMF 3 min/day for 21 days.	Affected expression of genes associated with immune cell infiltration, myelination, reactive oxygen species regulation, thyroid hormone transportation, cell proliferation, and cell migration. Data supports the beneficial effect of EMF stimulation in the repair process following traumatic brain damage.	
Rai et al. (2024b)	Brain of mini-swine traumatic brain injury model; 2.5 Hz and 3.5 Hz 1V sinusoidal EMF 3 min/day for 21 days.	Affected expression of genes: ADGR5 (immune and nervous system), LRRC2 (mitochondrial functions), and ATP8B3 (aminophospholipid transporter)	
Randhawa et al. (2025)	Human bone marrow-derived mesenchymal stem cells exposed to 10V-1 Hz pulsed EMF (35 oscillations/min). 30 min/day for 7 or 14 days.	Increased expression of ROS scavenging and ROS generating genes (glutathione peroxidase (GPX1b1, GPX1b2), selenoprotein thioredoxin reductase 1(TXNR1), NADPH oxidase 4 (NOX4), catalase (CAT), and superoxide dismutase 2 (SOD 2) genes. Transcriptomic changes also in other genes, e.g., osteoblast differentiation-related genes.	
Rao and Handerson (1996)	HeLa cells were transiently transfected with plasmids containing upstream	CAT expression observed after 5 min and peaked at 20 min of exposure.	

	regulating regions of c-fos coupled with the prokaryotic reporter gene CAT exposed to 60-Hz 0.006 mT EMF.	Expression returned to normal at 40 min.	
*Rao et al. (2002)	Human neuroblastoma IMR-32 cells exposed to 60 Hz 0.05, 0.1 or 0.2 mT EMF for 4 h.	No effect on APP695 gene expression	APP695 gene is related to the amyloid protein family, which is involved in αβ peptide production, a key factor in Alzheimer's disease.
Rasaeifar et al. (2023)	Transplanted mouse ovary tissues, 4.5 msec EM pulses, 15 Hz, 1.2 mT; 8 h/day from 2nd to 5th days after transplantation.	Affected expression of genes involved in angiogenesis, cell migration, vascularization and inflammation.	
Reale et al. (2006)	Human monocytes exposed to 50-Hz 1 mT EMF overnight.	Down-regulation of nitric oxide synthase (iNOS) and up-regulation of monocyte chemotactic protein-1 (MCP-1) genes	The monocyte chemotactic protein-1gene encodes a protein that is involved in the recruitment and activation of monocytes and macrophages.
Renáta Szemerszky et al. (2010)	Rats exposed to 50-Hz 0.5 mT EMF 8 h/day for 5 days or 24 h/day for 4-6 weeks.	Increased proopiomelanocortin mRNA level in anterior lobe of the pituitary gland following long-term exposure.	POMC is cleaved to give rise to multiple peptide hormones including α-MSH, ACTH, and endogenous opioids.
Reyes-Guerrero et al. (2010)	Adult male and female Wistar rats exposed to a 60-Hz magnetic field at 1 mT for 2 h/day for 9 days.	ELF EMF modulates estrogen receptor- beta gene expression in the olfactory bulb of female adult rats but not in males.	
Rodríguez-De la Fuente et al. (2012)	Plasmid labelled as pEMF electrotransferred into quadriceps muscles of	Increased luciferase gene expression.	

	mice that were later exposed to 60-Hz 0.08 mT EMF, 2 h/day for 7 days.		
Sadri et al. (2017)	Human mesenchymal stem cells derived from human newborn cords exposed to a static magnetic field of 12, 18, or 24 mT for 2 h.	Induced differentiation and decreased expression of Sox-2, Nanong, and Oct-4 genes (These genes are involved in embryonic organ development, maintenance of multipotency and self-renewal of undifferentiated embryonic stem cell.)	
Salek et al. (2021)	Mouse spermatogonial stem cells exposed to 50-Hz 2.5 mT EMF 1 h/day for 5 days.	Up-regulation of apoptotic gene (Caspase-3) and down-regulation of spermatogonial stem cells specific gene (GFRα1)	GFRα1gene encodes proteins that controls neuron survival and differentiation and play a role in the development of the nervous system.
Salari et al. (2023)	Brain of arts subjected to chronic unpredictable stress, injected with ketamine and exposed to 1a 10 Hz 10 mT EMF for 3 h/day for 3 days.	Increased gene expression of caspase-3, and reduced expression of brain-derived neurotropic factor (related to memory, neural plasticity, and emotional behavior) in the hippocampus; showed no effect on the expression of p53 and NMDA-Receptor.	
Sandberg et al. (2025)	Human bladder cancer cells (T-1147) exposed to 30 Hz EMF at 1.5- 16 mT, 1 h/day for 5 days.	Decreased expression of cancer related genes (JAK2, TGFβ2, and PIK3CD); increased expression of Rb1, CDKN1A, and TP53 genes.	JAK2-cell proliferation; TGFb2- promotility; PIK3CD- growth and increases cell invasion and metastasis Rb1- Tumor suppressor: halts cell cycle; CDKN1A-target of p53 and activation halts the cell cycle; TP53- Tumor suppressor: loss of function promotes cell division

Sanie-Jahromi et al. (2016)	Human breast adenocarcinoma MCF-7 and neuroblastoma SH-SY5Y cells exposed to 50-Hz EMF at 0.25 and 0.5 mT (5 min ON/5min OFF; 15 min ON/15min OFF, or 30 ON continuously) for 30 min.	mRNA levels of seven genes involved in DNA repair pathways down regulated in MCF-7 cells. Synergistic with cisplatin in MCF-7 and SH-SY5Y cells.	
Sanie-Jahromi and Saadat (2017)	MCF-7 and SH-SY5Y cells exposed to an intermittent (15 min OF/15-min OFF) 50-Hz EMF at 0.5 mT for 30 min. Cells were also treated with cisplastin and bleomycin.	EMF exposed MCF-7 cells treated with cisplastin and bleomycin showed more effects on some DNA repair gene expression compared with "cisplastin and bleomycin" treatment alone, while SH-SY5Y susceptibility was not changed between the two treatments.	
Sanie-Jahromi and Saadat (2018)	MCF-7 and SH-SY5Y cells were treated with 5.0 μM morphine and exposed to an intermittent (15 min ON/15 min OFF) 50-Hz EMF at 0.50 mT for 30 min.	Morphine treatment showed significant down-regulation of expression of genes involved in DNA repair pathways, while in "Morphine + EMF" treatment, the genes were not significantly changed.	
Selvamurugan et al. (2007)	Rat primary osteoblastic cells exposed to pulsed EMF (triangular pulses, pulse frequency of 3.8 kHz,	Increased alkaline phosphatase mRNA and three osteoblast marker genes during differentiation phase.	Alkaline phosphatase is an enzyme found throughout the body, primarily in the liver and bones. It serves as a marker for various diseases, including live and bone diseases.

	with a burst frequency of 1.5 Hz, a burst duration of 25.6 ms, and a burst period of 670 ms); 4 h/day during differentiation and mineralization phases.		
Selvamurugan et al. (2017)	Human bone marrow stromal cells exposed to pulsed EMF (15 Hz burst frequency and burst period of 67 ms) up to 120 min.	Affect expression of genes of cell cycle regulation, cell structure, and growth receptors or kinase pathways.	
Sendera et al. (2024)	Adipose-derived stem cells exposed to 50 Hz MF at 1.5 mT for 24 h.	Increased N6-methyladenosine (m^6A) RNA methylation. (Cell membrane flexibility, the metabolic potential of cells as well as the distribution, morphology, and metabolism of mitochondria were altered.)	
Seo et al. (2018)	Bone marrow-derived mesenchymal stem cells exposed to 50-Hz 1 mT EMF for 1 h.	Increased mRNA expression of growth factors (S100 (Schwann cell marker), glial fibrillary acidic protein (astrocyte marker), and brain-derived neurotrophic factor and nerve growth factor (neurotrophic factors) involved in nerve regeneration	

Seong et al. (2014)	Human bone marrow-mesenchymal stem cells exposed to a 50 Hz EMF at 1 mT for 8 days.	Increased expression of early growth response protein 1 (Egr1).	Growth response protein 1 is a transcription factor involved in tumor suppression, neuronal activity, neuronal plasticity, memory formation, fibrinogenesis, and ovarian functions.
Sharma et al. (2021)	Cumulus cells and buffalo somatic cell nuclear transfer (SCNT) embryos exposed to 0.03 mT pulsed EMF for 3 h.	Altered the expression level of several important genes related to pluripotency, apoptosis, metabolism, and stress.	
Shokrollahi et al. (2018)	Soybean plants exposed to static magnetic field at 20 and 30 mT for 5 h/day for 5 days.	Exposure to 20 mT decreased gene expression of Fe transporter, ferrous and H_2O_2 contents and gene expression, content and activity of ferritin and catalase. Opposite responses were observed at 30 mT exposure. Tertiary structures of ferritin, apoferritin and catalase altered by static magnetic field.	
Sobhanifard et al. (2019)	Spleen and thymus of rats injected with human serum albumin (HSA) and exposed to 50-Hz (0.001, 0.1, 0.5, or 2 mT) EMF; 2 h/day for 60 days.	Expression of T-bet and GATA-3 mRNA (genes involved in T-helper cell functions) decreased in the spleen in rats exposed to 0.001 and 0.1 mT.	
Song et al. (2024)	Rat bone marrow-derived mesenchymal stem cells exposed to	Increased gene expression of ACAN, COL2A, and SOX9 (bone anabolic) expression; decreased MMP3 and MMP13	

	75 Hz pulsed EMF for 7 days at 3 mT.	(bone catabolic) expression- proteins involved in chondrocyte maturation and long bone development. Chondrogenesis was observed. It was proposed that PEMF acts on sFR3 protein that inhibits Wnt/β-catenin signaling pathway. Results also observed in mice in vivo (75 Hz, 3 mT, 7 days). PEMF may be useful for treatment of knee osteoarthritis.	
Soydas et al. (2024)	Aged mouse fibroblasts exposed to 50-Hz EMF at 5 mT for 1 h.	Increased gene expression of MMP2 and MMP9 (involved in breakdown of extracellular matrix, embryonic development, tissue remodeling wound healing), RELA and NF-κB (transcription factors involved in cancer development), and CDH1 (involved in various types of cancer). Effects attenuated by metformin (an NF-κB inhibitor).	
Sun L et al. (2019)	*Irpex lacteus*, a white-rot fungus, exposed to a 50-Hz magnetic field ay 3.5 mT for 3 h/day for 4 days.	Global gene expression changes were observed.	

Sun L-Y et al. (2010)	Human bone marrow mesenchymal stem cells exposed pulsed EMF (15 Hz in 20 pulses at 4.5 ms burst); peak 1.8 mT, 8 h/day for 7 days.	Increased expression of the key osteogenesis regulatory gene cbfa1.	The CBFA1 gene is crucial for osteoblast differentiation and skeletal development.
*Sun W. et al. (2010)	Trophoblasts from first trimester human chorionic villi at 8-10 weeks' gestation exposed to 50-Hz, 0.4 mT for 72 h.	No effect on mRNA levels of apoptosis-related genes bcl-2, bax, caspase-3, p53, and fas.	
Suryani et al. (2019)	Calvarial osteoblast precursor cells exposed to 50-Hz 0.6 mT EMF 15-60 min/day for 28 days.	Up-regulation of osteogenic genes	
*Takahashi and Furuya (2023)	Human Hematopoietic Stem/Progenitor Cells exposed to 50-Hz MF at 300 mT for 35 days.	No effect on expression levels of recombination-activating genes RAG1 and RAG2 in the B cells	RAG complex is a multiprotein complex that mediates the DNA cleavage phase during V(D)J recombination. This complex can make double-strand breaks by cleaving DNA at conserved recombination signal sequences (RSS).
Tang et al. (2025)	Mouse spinal-cord derived neuronal stem cells exposed to 50 Hz MF at 0.2, 0.5 or 1 mT; 1 h/day for 3 days.	Dose-dependent increase in expression of NeuN (involved in neuronal development and function) and Sox2 (involved in renewal of neural embryonic stem cells and tissue formation) genes.	
Tasset et al. (2013)	Effect of transcranial magnetic stimulation on Huntington's disease-like rat model induced by 3-	Modulated the Nrf2 transcription factor in the brain (increase in (cytoplasm and nucleus)	NRF2 is a transcription factor that regulates the expression of antioxidant enzymes, protecting cells from oxidative stress and inflammation.

	nitropropionic acid (3-NP).		
Tian F et al. (2002)	Ku80-deficient cells (xrs5) and Ku80-proficient cells (CHO-K1) irradiated by X-ray and then exposed to 60-Hz 5 mT EMF for 24 h.	In xrs5 cells, EMF suppressed the apoptosis effect of X-ray by decreasing the levels of caspase-3, p21, p53 and phospho-p53 and by increasing bcl-2 gene expression (apoptosis related genes).	BCL2 blocks apoptosis.
Tian L et al. (2022)	Male C57BL/6J mice exposed to hypomagnetic field (i.e., with the geomagnetic field eliminated) for 8 weeks.	Increased reactive oxidative species in hippocampus by modulating hypomagnetic-regulating genes (Nox4, Gpx3). Mice showed cognitive deficits.	
Tipping et al. (1999)	*Drosophila* larvae exposed to 50-Hz 0.008 mT MF for 20 min.	Decreased transcript levels of HSP 70a, Histone 1.9, and Copia.	HSP70A is involved in ensuring correct folding of proteins and the re-folding of misfolded proteins. Hi-9 gene encodes a protein that plays a role in chromatin remodeling during mammalian spermatogenesis. Copia superfamily is a group of long terminal retrotransposons in eukaryotic genome. (Retrotransposons are mobile elements which move in the host genome by converting their transcribed RNA into DNA through reverse transcription.)
Turan et al. (2026)	Liver from rats with liver damage induced by lipopolysaccharide (LPS) exposed to pulsed magnetic field (0.5 mT for 3 h), 27.12 MHz RFR (30 min, no dosimetry data), or both EMFs.	Reversed LPS-induced changes in expression of genes involved in oxidative process (NRF2, SOD); inflammation (TNF-α); ER stress (PERK, Capase-12, Capase-3), and mitochondrial apoptosis process (BCL2, BAX, Cyt-C, Caspase-9). Combined MF and RFR more effective.	

Vergallo et al. (2020)	Human peripheral blood lymphocytes exposed to 6 mT static MF.	modulates gene expression of ATP-binding cassette transporter A1 (ABCA1) (promotes cellular phospholipid and cholesterol efflux)	
Vincenzi et al. (2012)	PC12 rat adrenal pheochromocytoma and U87MG human glioblastoma cell lines exposed to pulsed EMF (75 Hz, 1.3 ms duration, 0.1 duty cycle) at 1.5 mT for 24 h.	Increased A_{2a} and A_3 adenosine receptor mRNA (Inhibit cancer growth)	
*Vinod et al. (2020)	Human articular cartilage derived chondroprogenitors exposed to pulsed EMF (15 Hz, 6 ms duration, 2 mT) 10 min or 10 min every 3 days for 21 days (7 exposures).	No effect on gene expression of ACAN, SOX9, COL2A1, TGFβ1, TGFβ2, and TGFβ3	
Wang J. et al. (2013)	Human fetal scleral fibroblasts exposed to 50-Hz 0.2 mT EMF for 24 h.	Suppressed type I collagen (COL1A1) and fibroblast growth factor-2 (FGF2) mRNA expression; increased matrix metalloproteinases-2 (MMP-2) and transforming growth factor-β2 (TGFβ2) mRNA expression	COL1A1 is involved in extracellular matrix. Fibroblast growth factor is involved in embryonic development, cell growth, morphogenesis, tissue repair, tumor growth and invasion. Metalloproteinase-2 is involved in the breakdown of extracellular matrix components. TGFβ2 gene encodes a protein involved in cell growth, differentiation, motility, and apoptosis.

Wang L et al. (2021)	Female mice exposed to 8, 50, or 75 Hz 1.6 mT pulsed EMF 1 h/day for 4 weeks.	50 and 75 Hz promoted expression of the osteoblast-related genes (ALP, OCN, Runx2) and suppressed osteoclast-related gene expression (CTSK, NFATc1, TRAP)	
Wang Q et al. (2014)	Human amniotic epithelial cells exposed to 50 Hz pulsed EMF (applied field increased from 0 to 1 mT in 1.5 ms and then decayed back to 0 in 5 ms) 30 min twice a day for 21 days.	Increased expression of osteoblast specific genes including alkaline phosphatase and osteocalcin; gene expression of BMP-2, Runx2, β-catenin, Nrf2, Keap1 and integrinβ1 were up-regulated in the osteogenic differentiation of amniotic epithelial cells.	
Wang T. et al. (2025)	Bone marrow-derived mesenchymal stem cells of mouse exposed to pulse EMF at 8 Hz, 3.8 mT, square-waves burst and pulse widths 62.5 ms; 1h/day for 4 weeks.	Increased osteogenesis (Runx2 and Alp) and decreased adipogenesis (Pparg, Cebpa, and Fabp4) gene expression-only in the presence of dorsal root ganglion sensory neurons that secrets semaphorin 3A (Sema3A). (Sema3A interacts with neuropilin-1 (Nrp1) in MSCs that express the leptin receptor, aiding osteogenesis and inhibiting adipogenesis in aging male mice).	
Wang Y. et al. (2020)	*Caenorhabditis elegans* exposed to	Expression levels of the *r53.4, hpo-18, atp-5*,	

	50-Hz, 3 mT EMF for 15 generations.	and *atp-3* genes encoding ATPase and *sod-1, sod-2,* and *sod-3* genes encoding superoxide dismutase (SOD) were significantly upregulated.	
Wang Y et al. (2023)	Mouse model of myocardial infarction, 30 Hz, 3 mT, 45 min/day for 14 days.	Down regulation of expression of miR-20a-5p; protected ischemia myocardium by regulating the miR-20a-5p/E2F1/p73 signaling pathway; synergistic with adipose-derived stem cell treatment.	
Wang Z et al. (2009)	Human embryoid body derived (hEBD) LVEC cell line exposed to 0.23-0.28 T static magnetic field for 24 h.	Gene expression in cells showed nine signaling networks responding to static magnetic field	
Wei J. et al. (2026)	Bone marrow mesenchymal stem cell treated with dexamethasone exposed to 75 Hz EMF at 1.5 mT 4 h/day for 3 days.	EMF reversed dexamethasone-induced decrease in expression of osteogenic genes (RUNX2, COL1A1, SP7, BGLAP) and increases in expression of adipogenic genes (PPAR-γ, C/EBP α, FABP4, ADIPOQ).	
Wu et al. (2018)	C3H10T1/2 mesenchymal cells were exposed to 30-Hz, 1 mT pulsed EMF, 2 h/day for 3 days.	Promoted the gene expression of the Wnt/β-catenin pathway. Calcium involved.	The Wnt/β-catenin pathway is involved in cell fate, proliferation, and differentiation.

Wydorski et al. (2023)	Porcine endometrial slices exposed to 50 Hz EMF at 8 mT for 2 h.	Increase or decrease in DNA methylation depending on promoter regions.	
Wydorski et al. (2024a)	Porcine endometrial slices exposed to 50 Hz EMF at 8 mT for 2 h.	Changes in expression of certain genes, with DNA methylation and micoRNA changes.	
Wydorski et al. (2024b)	Porcine endometrial slices exposed to 50 Hz EMF at 8 mT for 2 h.	Decreased CASP7 and increased NOS3 mRNA transcripts; Increased *CIDEB*, *GADD45G*, and *TP53I3* mRNA transcripts. (Genes involved in apoptosis and oxidative stress).	CASP7 gene encodes Caspase-7 which is an executioner protein of apoptosis. The NOS3 gene encodes the enzyme nitric oxide synthase 3, which is crucial for producing nitric oxide (NO) in the vascular endothelium, playing a vital role in cardiovascular health. The CIDEB gene plays a crucial role in lipid metabolism and has been linked to protection against liver diseases. GADD45 gamma is a protein that is involved in sexual development, human-specific brain development, tumor suppression, and the cellular stress response. GADD45G interacts with several other proteins that are involved in DNA repair, cell cycle control, apoptosis, and senescence. *TP53I3* gene encodes a protein involved in cellular responses to oxidative stress and plays a role in p53 mediated cell death.
Xu C et al. (2021)	*Arabidopsis* (rockcrest) exposed (from seed to 5 day old fruit).to near-null magnetic field (hypomagnetic field) (compared with plant grew in geomagnetic field).	Expressions of GA(gibberellin)20-oxidase (GA20ox) genes (GA20ox1 and GA20ox2) and GA3-oxidase (GA3ox) genes (GA3ox1 and GA3ox3) in fruits downregulated. Effects not found in cryptochrome double mutant, cry1/cry2 indicating that suppression of fruit growth by the near-null magnetic field is	

		mediated by cryptochrome.	
Yahyapour et al, (2022)	Human T98 glioma cells exposed to 50-Hz 10 mT EMF.	Increased apoptosis-related gene and Autophagy-related gene expression. (Synergistic with ionizing radiation and temozolomide.)	
Yang et al. (2024)	Human umbilical vein endothelial cells exposed to 2 ms square pulsed EMF at 80 Hz, 4 mT, 30 min/day for 2 days.	Increased expression of GLUT ½ gene (glucose transport across plasma membrane) and genes (PFKL, PFKLM, PFKP, PKM2, and HK2) encoding the three key regulatory enzymes of glycolysis, hexokinase, phosphofructokinase, and pyruvate kinase, increased expression of DRP1 and FS1 and decreased HFN1/2 and OPA1 genes (mitochondrial fission genes). (Increased mitochondrial fission observed.)	Drp1 is a fundamental component of mitochondrial fission. FS1 gene plays a role in the development of the hand and foot. HFN1/2 gene encodes a transcription factor that plays a role in the growth and development of beta cells in the pancreas. OPA1 gene encodes a protein involved in mitochondrial function and is associated with neurological disorders.
Yao et al. (2015)	Rat Schwann cells exposed to DC electric field for 36-72 h at 50, 100, or 200 mV/mm.	Differential expression of genes participate in multiple cellular signaling pathways involved in the regulation of cell migration, including pathways of regulation of actin cytoskeleton, focal adhesion, and PI3K-Akt cell cycle regulation).	The PI3K-Akt signaling pathway is involved in cell survival, growth, proliferation, cell migration, and angiogenesis.

Yao et al. (2019)	Oligodendrocyte precursor cells (OPC) (that can differentiate into oligodendrocytes) exposed to 50-Hz 1.8 mT square-wave pulsed EMF, 2 h/day for 3, 7, 14, and 21 days.	Up-regulated miR-219-5p (associated with OPC differentiation) and down-regulated Lingo1 (involved in myelination) expression. EMF promoted OPC differentiation.	
Yap et al. (2025)	Chest muscle of quail embryos in eggs exposed to pulsed EMF (15 Hz repetition rate at 1.5 mT); 10 min per days for 5 days within two weeks.	Increased gene expression of PPAR-a, SIRT1, COL1A1. And COL3A1 (Genes involved in promoting oxidative muscle development, mitochondriogenesis, and angiogenesis,) Effects depended on polarity of field.	
Yomori et al. (2002)	Human glioblastoma (T98G) cells exposed to elliptically polarized 60-Hz MF at 1, 20, 100, or 500 μT for up to 3 h.	No effect on c-fos, c-jun, and c-myc gene expression	
Yun et al. (2022)	Mouse melanoma B16-F10 cells in DC electric fields (0-500 mV/mm) for 3 h.	cells migrated toward the cathode in a voltage-dependent manner; Approximately 3000 upregulated and 2613 downregulated genes were identified under DC electric field. Some genes correlated with cell migration.	
Zavarch et al. (2021)	Human gastric adenocarcinoma cell line (AGS) exposed to	Up-regulation of miR-144 and miR-375 (involved in	

	50-Hz EMF at 0.2 and 2 mT for 18 h, continuously and discontinuously (1.5 h on/1.5 h off).	cell proliferation and tumor suppressor).	
Zhang H et al. (2016)	ICR mice exposed to a 50-Hz EMF at 8 mT for 4 h/day for 28 days.	Declined DNA content and increased expression of apoptosis genes in spleen. Free radicals may be involved.	
Zhang M et al. (2020)	*Onchidium struma* (a mollusk) exposed to 50-Hz 0.1 or 0.5 mT EMF for 24, 72, or 168 h.	There were 341 differentially expressed genes (DGEs) between unexposed and exposed groups, including 209 up-regulated and 132 down-regulated genes with those associated with immune response.	
Zhang X-J et al. (2023)	Rats exposed to electromagnetic pulses (1 Hz pulse, 700 kV/m, 400 pulses).	Found 41 differentially expressed long non-coding RNA and 266 differentially expressed mRNAs (with genes associated with synapse- and metabolic-related pathways) between EMP and sham groups	
Zhang Y et al. (2022)	*Nilaparvata lugens* (brown planthopper insect) exposed to hypomagnetic field (<0.005 mT) during developmental from juveniles to adults.	Different reference-gene expressions were observed at different stages of development.	

Zheng et al. (2018)	dental pulp stem cells exposed to a static magnetic field of 1,2, 4 mT for 15 min, 30 min, 1 h or 24 h.	Increased expression of several growth factors (FGF-2, TGF-β, and VEGF), migration genes (MMP-1 and MMP-2), and upregulated the two YAP/TAZ-regulated genes, CTGF and ANKRD1. (YAP/TAZ are transcriptional activators particularly involved in cancer cell proliferation, therapy resistance and metastasis. Increased cell proliferation, osteo/odontogenesis and mineralization observed in the stem cells).	
Zhou et al. (2023)	*Geobacter sulfurreducens* exposed to static MF at 100 mT for 16 h or 8 h ON/8 h OFF.	Increased expression of genes involved in electron transfer.	
Zhou et al. (2024)	Rats exposed to 8 Hz pulsed MF (square-wave trains of 0.2 ms width pulses with 0.5 ms between pulses; 25 sec On/100 sec OFF) at 3.82 mT; 40 min/day, 5 days/week for 12 weeks.	MF attenuated in bone marrow age-related increased expression of genes related to immune and inflammation responses (NLRP3, caspase 1, IL-1β, and GSDMD). Pulsed MF mitigates aging-induced bone loss and reverses the deterioration of bone microarchitecture.	
Zhou et al. (2025)	Human chondrocytes (C28/I2) stimulated	Compared to (IL)-1β-treated cells, (IL)-1β + EF	

	with interleukin (IL)-1β exposed to 75 Hz, 1.5 mT EMF for 24 h.	cells showed decreased MMP12 and ADAMT55 gene expression (genes involved in cartilage degradation), and increased expression of Col2a1 and ACAN (genes involved in collagen production and cartilage structure and function). EMF may counteract anti-inflammatory effect of osteoarthritis (OA).	
Zywicka et al. (2025)	*Komagataeibacter Xylinus* exposed to a rotating MF, 5 and 50 Hz for 12-72 h at 17-22 mT.	Increased expression of bacterial cellulose-synthase genes	