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RFR and gene expression

 # Study in which wireless devices were used in exposure; LI- Study reported effect at low SAR (< 0.4 W/kg); * Study reported no significant effect

	Exposure conditions	Results	Gene Functions/peptide coded
#Akhavan-Sigari et al. (2014)	Resected Glioblastoma multiforme (GBM) from human subjects.	Increased mutant type of p53 gene expression in the peripheral zone of GBM in patient who use cell phone form ≥3h/day; the increase was significantly correlated with shorter overall survival time.	Tumor protein p53 conserves stability by preventing genome mutation and prevents cancer development. It is often mutated in human cancers.
Akin et al. (2025)	Lung of pulmonary ischemia-reperfusion rat model- rats simultaneously exposed to 27.12 MHz RFR; 60 min at 10 V/m (no dosimetry data).	RFR attenuated ischemia-reperfusion-induced increase in HIF-1α, eNOS and BAX; and decrease in BCl2 gene expression. (RFR alone had no effect on these genes.)	Overexpression of HIF-1α by hypoxia is implicated in cancer biology, as well as angiogenesis, energy metabolism, cell survival, and tumor invasion. Nitric oxide produced by eNOS in the vascular endothelium plays crucial roles in regulating vascular tone, cellular proliferation, leukocyte adhesion, and platelet aggregation. BAX is a pro-apoptosis protein. BCL2 blocks apoptosis.
Albaqami et al. (2020)	Arabidopsis (rockcress) seedlings exposed to 7 MHz RFR, 2 μT (rms); 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. PIN1 and PIN3 are plasma membrane proteins that regulate auxin efflux from plant cells. Auxin is a class of growth regulator phytohormones, of which indole-3-acetic acid (IAA) is a member.

Almášiová et al. (2025)	Mesonephros (temporary urinary excretory system in developing animals) of chick embryos (in eggs) exposed to 2450 MHz RFR for 9 days; 0.00002 - 0.00005 mW/cm^2.	Up-regulation of caspase-1 gene expression (increased apoptosis and cell proliferation)	Caspase-1 plays a role in cell immunity as an inflammatory response initiator. It initiates apoptosis in response to certain stressors such as pathogen infection.
An et al. (2023)	Mouse embryonic neural stem cells exposed to 1950 Hz RFR for 48 h at 2 W/kg.	Altered gene expression of Bbs1, Slc38a3, and Vps18 genes.	Bbs1, Slc38a3, and Vps18 are involved in neurodevelopment and brain functions.
Arslan et al. (2024) (LI)	Brain of rats exposed to 189 MHz RFR (217 Hz modulation); 2 h/day for 8 weeks at 0.06 W/kg.	p38MAPK gene expression up-regulated, no effect on Hsp27 gene expression	p38 mitogen-activated protein kinases are a class of mitogen-activated protein kinases (MAPKs) that are responsive to stress stimuli, and are involved in cell differentiation, apoptosis and autophagy. The main function of Hsp27 is to provide thermotolerance *in vivo*, cyto-protection, and support of cell survival under stress conditions. inhibiting protein aggregation and by stabilizing partially denatured proteins. It has antiapoptotic properties and roles in cell growth (termination) and inflammatory and stress responses.
#Azimipour et al. (2020)	Pre-antral ovary follicles of mouse exposed to radiation from a Sony Ericsson K800 for 1 h (no dosimetry data available).	Increased the matrix metalloproteinases MMP-2 gene and decreased MMP-9 gene expression; decreased expression of tissue inhibitors of metalloproteinases (TIMPs) genes, TIMP-1 and -2.	Matrix metalloproteinases (MMP) are proteases capable of degrading all kinds of extracellular matrix proteins. They cause release of apoptotic ligands and are involved in cell proliferation, migration (adhesion/dispersion), differentiation, angiogenesis, apoptosis, and host defense. TIMP-1 and -2 are natural inhibitors of MMP. TIMP-1 plays a crucial role in extracellular matrix composition, wound healing, and pregnancy. It is involved in

			implantation and regulates the transcriptional profile of fetal and placental tissues associated with the early stages of pregnancy. TIMP-2 is involved in pulmonary functions.
#Balakrishnan et al. (2014)	Serum of mobile phone frequent and infrequent users.	Increased Hsp70 gene expression with phone use.	Hsp70 stabilizes partially synthesized protein and prevents aggregation, protects cells from thermal and oxidative stress, disposal of damaged proteins, and inhibits apoptosis.
Balci et al. (2025)	Kidney of rats with acute kidney injury caused by lipopolysaccharide (LPS) exposed to 27.2 MHz RFR at 10 v/m for 3 h.	RFR reversed effects of LPS on gene expression of IL-6, HIF-1a, eNOS, Bcl-2, and Cas9. (1 second MF-square pulses at 0.5 mT (0.5 h) has similar effect but not synergistic with RFR).	Interleukin 6 (IL-6) is an interleukin that acts as both a pro-inflammatory cytokine and an antiinflammatory myokine. Osteoblasts secrete IL-6 to stimulate osteoclast formation. HIF-1a 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. Bcl-2 blocks apoptosis. Cas9 (CRISPR associated protein 9) plays a vital role in the immunological defense of certain bacteria against DNA viruses and plasmids.
Beaubois et al. (2007)	tomato plants (Lycopersicon esculentum) exposed 90 MHz RFR at 5 V/m for 10 min.	Increased wound-inducible transcript bZIP.	Basic leucine zipper (bZIP) gene is one of the transcription factor families in plants, and plays important roles in light signaling, seed maturation, flower development as well as abiotic and biotic stress responses.

Bertuccio et al. (2023)	Human neuronal-like SH-SY5Y and peripheral blood mononuclear cells to 2450 MHz RFR for 2. 24, or 48 h; 1.8 V/m at 20 cm from antenna.	Changes mRNA expression of mitochondrial transcription factor A (mtTFA), superoxide dismutase 1 (SOD1), and microtubule-associated protein 1A/1B-light chain 3 genes.	mitochondrial transcription factor activates mitochondrial transcription and involved in mitochondrial genome replication. It affects embryonic development. SOD1 is antioxidant enzyme. Microtubule-associated proteins 1A/1B light chain 3B is involved in the autophagy pathway.
Bertuccio et al. (2024)	Human neuronal-like SH-SY5Y and peripheral blood mononuclear cells to 2450 MHz RFR for 24h, no dosimetry data.	Decreased Nrf2 (transcription factor for stress response) and SOD2 gene expression in both cell types; increased BAX/BCL2 ratio (apoptosis-related) gene expression in SH-SY5Y only (with increased in caspase level).	Nuclear factor erythroid 2-related factor 2 (NRF2) is involved in the cellular defense against toxic and oxidative insults through the expression of oxidative stress response and drug detoxification genes. SOD2 is an ani-oxidant enzyme. BAX is a pro-apoptosis protein that affects the voltage-gated anion channels on mitochondrial membrane.
Bourdineaud et al. (2017) (LI)	Eisenia fetida earthworms exposed to 900 MHz for 2 h; SAR 0.00013-0.00933 W/kg.	DNA genotoxic effect persisted for at least 24 h; gene expressions up regulated for Hsp70, MEKKI (signal transduction); oxidative stress; and chemical and immune defenses.	Heat shock proteins (Hsps) are produced by cells in response to stressors. They stabilize new proteins to ensure correct folding or by refolding proteins that were damaged by cell stress. MEKK1 are kinases connecting cell-surface receptors to specific transcription factors and other regulatory proteins, thus allowing extracellular signals to regulate the expression of specific genes. MEKK1 suppresses oxidative stress-induced apoptosis.
*Bourthoumieu et al. (2013)	Human amniotic cells exposed to GSM-900 MHz RFR for 24 h; SAR 0.25, 1, 2, and 4 W/kg.	No significant change in the expression and activation of the p53 protein was found.	p53 can cause cell cycle arrest and allow time for DNA repair or apoptosis.
Buttiglione et al. (2007)	Human SH-SY5Y neuroblastoma cells exposed to modulated 900 MHz RFR for 24 h; SAR 1 W/kg.	Increased Egr-1 gene expression paralleled with activation of the MAPK subtypes ERK1/2 and SAPK/JNK, and decrease in mRNA of Bcl-2 and surviving genes. RFR has anti-proliferative effect and causes cell cycle arrest at G2-M.	Early growth response protein-1 (Egr-1) is a transcriptional regulator in the brain. The products of target genes it activates are required for differentiation and mitogenesis. It is a tumor suppressor gene and has a role in neuronal plasticity. Stress-

			activated protein kinases (SAPK)/Jun N-terminal kinases (JNK) are activated by a variety of environmental stresses, inflammatory cytokines, and growth factors.
Cantu et al. (2023) (LI)	Human keratinocytes exposed to 900 MHz RFR for 1 h at 0.00155 W/kg.	Six common DNA targets were both differentially methylated and differentially expressed.	Six genes related to cell survival and responses to damage were affected (SPDYA, BBS5, CCS, DOK3, DD12, and MGA). Particularly, down-regulation of docking protein-3 (DPK3) could negatively regulate C-Jun N-terminal kinase (JNK) leading to apoptosis. Up-regulation of DNA-damage induced 1 homolog 2 (DD12) increases cell survival following stress.
*Cantu et al. (2024)	Rat primary hippocampal neurons exposed to 300 MHz RFR for 1 h or 1 h/day on 3 consecutive days at 0.57 or 5.91 W/kg.	No effect on 20 differentially expressed genes at low SAR; significant upregulation at high SAR with a significant temperature increase (41°C).	
Cappucci et al. (2022) (LI)	Head, ovary, and testis of Drosophila melanogaster exposed to 2437 MHz RFR (Wi-Fi) from embryo to adult stage at 0.0608 W/kg.	Increased gene expression of Hsp70, induced gene instability, and increased DNA damage.	Hsp70 stabilizes partially synthesized protein and prevents aggregation, protects cells from thermal and oxidative stress, disposal of damaged proteins, and inhibits apoptosis.
Cervellati et al. (2013)	Human placenta trophoblast-derived HTR-8/SVneo cells exposed to 1.8 GHz GSM RFR amplitude modulated by rectangular pulses of 217 Hz for 1 h; SAR 2 W/kg.	Increased connexin Cx40 and Cx43 mRNA expression; decreased Integrin alpha1 and β 1 mRNA levels but enhanced Int alpha5 mRNA expression.	Connexin-40 (Cx40) gene encodes a gap junction protein involved in cell-cell communication in cardiomyocytes of the atria and cardiac conduction system and endothelial cells of large arteries. Connexin 43 (Cx43) protein is a component of gap junctions, which allow communication between cells to regulate cell death, proliferation, and differentiation. It plays a role in

			embryonic development, inflammation, and spermatogenesis. Integrins are known to participate in cell-surface-mediated signaling.
*Chauhan et al. (2006a)	Human lymphoblastoma cells (TK6) exposed to pulsed-modulated, intermittent (5 min ON, 10 min OFF) 1900-MHz RFR for 6 h; SAR 1 or 6 W/kg.	No evidence of a general stress response with proto-oncogene and heat-shock protein gene transcriptions.	
*Chauhan et al. (2007)	Human glioblastoma-derived cell-line (U87MG) and human monocyte-derived cell-line (MM6) exposed to pulsed-modulated, intermittent (5 min ON, 10 min OFF) 1900-MHz RFR for 24 and 6 h; SAR 0.1-10 W/kg.	No evidence that the RFR exposure altered late onset gene expression in either cultured cell-lines. (Hsp 40, 27, and 105 were studied).	Hsp 40 (chaperone DnaJ) associates with unfolded polypeptide chains and prevents their aggregation Hsp 27 is a chaperone of the sHsp (small heat shock protein) is involved in thermotolerance, inhibition of apoptosis, regulation of cell development, cell differentiation, and support of cell survival under stress conditions. The cytoprotective properties of Hsp 27 result from its ability to modulate reactive oxygen species and to raise glutathione levels. Hsp 105 regulates biogenesis and control of Misfolded proteins.
Chen C et al. (2021)	Neural stem cells-derived neurons and retinoic acid-induced Neuro-2A cells exposed to 1800 MHz GSM-talk mode signal (5 min ON/10 min OFF) for 48 h at 4 W/kg.	Gene expression of Eph receptors 5 (EPHA5) was inhibited.	EPHA5 is required for neurite outgrowth.
Chen G et al. (2012)	Saccharomyces cerevisiae yeast cells exposed to 1800 MHz RFR for 6 h; SAR 4.7 W/kg.	Expressions of structural maintenance genes of chromosomes 3 (SMC3) and aquaporin 2 (AQY2 (m), whereas three other genes: halotolerance protein 9 (HAL9), another kinase 1 (YAK1) and	SMC3 is a subunit of the cohesin complex which mediates sister chromatid cohesion, homologous recombination and looping. The other genes are

		one function-unknown gene (open reading frame: YJL171C), showed opposite changes in expression.	involved in salt stress and growth of the bacteria.
Cheon et al. (2023)	SK-MEL-3 melanoma cells exposed to a pulsed 1.6 THz RFR (1 kHz repetition) for 1-48 h at 14.7 mW/cm^2.	downregulated genes involved in cancer and apoptosis pathways (FOS, JUN, and CXCL8), DNA demethylation involved.	FOS is involved in cell proliferation, differentiation, survival, and in cancer development. c-jun is an oncogenic transcription factor. It is required for progression through the G1 phase of the cell cycle. It has anti-apoptotic activity and is required for tumor cell survival between the initiation and progression stages. IL-8 (CXCL8) induces chemotaxis in target cells, primarily neutrophils, causing them to migrate toward the site of infection. It also stimulates phagocytosis once they have arrived. IL-8 is also known to be a potent promoter of angiogenesis.
Chow et al. (2024)	Human umbilical vein endothelial cells exposed 6.78 MHz RFR at 10 µT for 24 h.	Increased expression of genes involved in promotion of cell proliferation and reduction of oxidative stress (carbonic anhydrase 8 (CA8), aldo-keto reductase family members including AKR1C1 and AKR1C3 and malic enzyme).	
Costantini et al. (2022)	Human karotinocytes (HaCat) cells exposed to 27.1 MHz pulse-modulated at 600 Hz RFR for 2 x 30 min, 6 h, or 24 h. (No dosimetry data.)	Affected gene expression of cytokines (IL4 and IL6), and matrix metalloproteinases related to wound healing depending on exposure conditions.	IL4 stimulates activated B cell and T cell proliferation, and the differentiation of B cells into plasma cells. It is a key regulator in humoral and adaptive immunity. IL6 is an interleukin that acts as both a proinflammatory cytokine and an antiinflammatory myokine. osteoblasts secrete IL-6 to stimulate osteoclast formation.
Czyz et al. (2004)	Pluripotent embryonic stem (ES) cells (wild-type and deficient for the tumor suppressor p53 exposed to	Upregulation of mRNA levels of the heat shock protein, Hsp70 and a low and transient increase of c-jun, c-myc, and p21 levels in p53-deficient, but not in wild-type cells.	Hsp70 stabilizes partially synthesized protein and prevents aggregation, protects cells from thermal and oxidative stress, disposal of damaged proteins, and inhibits apoptosis.

	pulsed 1710 MHz RFR at GSM-217 (1.5 W/kg) or GSM-talk (0.4 W/kg) mode for 6-48 h.		c-jun is an oncogenic transcription factor. It is required for progression through the G1 phase of the cell cycle. It has anti-apoptotic activity and is required for tumor cell survival between the initiation and progression stages. c-myc gene is a transcription factor that regulates cell cycle progress, proliferation, growth, adhesion, differentiation, apoptosis, and metabolism. p21 represents a major target of p53 activity and is associated with linking DNA damage to cell cycle arrest.
Dahon et al. (2025)	Human embryonic kidney HEK293 cells exposed to 1800 MHz RFR at 11 x 10^{-4} mW/cm^2-0.66 x 10^{-4} $\mu W/cm^2$ for 15 min.	Increased expression of oxidative processes related genes (KIAA, KRT79, RPS, GPX-1, SOD2). (Dose response nonlinear.)	KIAA gene promotes degradation of SLC43A2 mRNA. Downregulation of SCL43A2 reduces oxidative stress. KRT79, are filament proteins that make up one of the major structural fibers of epithelial cells. The RPS gene product reduces oxidative stress induced cellular damage via a ribosomal-related process. GPX and SOD are antioxidant enzymes.
Dasdag et al. (2015a) (LI)	Brain of rats exposed to 900 MHz RFR 3h/day. 7 day/week for 12 months; 0.0369 W/kg.	Decreased rno-miR107; no effect on levels of other miRNA studied.	Involved in cancer progression.
Dasdag et al. (2015b) (LI)	Brain of rats exposed to 2450-MHz RFR 24 h/day for 1 year; 0.004 W/kg.	Decreased expression of microRNA miR-106b-5p and miR-107.	miR-106b-5p acts as a oncomiR or tumor suppressor via regulating almost all cancer cell biological processes, including cell cycle, proliferation, apoptosis, differentiation, invasion, angiogenesis, drug resistance and metastasis.

Dasdag et al. (2019) (LI)	Brain of rats exposed to 900 MHz FR 3 h/day (7 days a week) for 12 months, 0.198 W/kg.	Increased expression of rno-miR-145-5p (no effect on several other miRNA).	A tumor suppressor miRNA in diverse types of cancers, including bladder cancer, breast cancer, cervical cancer, cholangiocarcinoma, renal cancer, and gastrointestinal cancers.
Dasdag et al. (2022) (LI)	Brain of rats exposed to 2400 MHz RFR emitted from a Wi-Fi generator feed to an antenna for 24 h/day for one year; 0.000328 W/kg.	Increased rno-miR-181a-5p and membrane lipids.	MiR-181a-5p regulates angiogenesis, inflammatory response and obesity. It exerts regulatory influence on cancer development and progression.
Dasgupta et al. (2022)	Zebrafish exposed to 3.5 GHz RFR from 6 h post-fertilization to 48 h; 8.27 W/kg.	A modest transcriptomic disruption at 48 h post-fertilization, with 28 differentially expressed genes (e.g., hnrnpdl (a pre-RNA processing and RNA metabolism gene) and mkrn2 (a protein modification gene)); biochemical pathways related to metabolism and nucleic acid synthesis were significantly perturbed.	
*Dawe et al. (2008)	transgenic Hsp16-1::lacZ strain of Caenorhabditis elegans exposed to 1800 MHz RFR (continuous-wave or talk-pulsed) for 2.5 h at 1.8 W/kg.	No effect on Hsp16-1 heat-shock gene expression.	Hsp-16.1 mediate cyto-protection from hyperthermia.
#Deena et al. (2025)	Human SH-SY5Y neuroblastoma cells; 2400 MHz RFR from cell phones; 4 h; no dosimetry data.	Increased BAX gene expression, no effect on Bcl2 expression (increased apoptosis).	BAX is a pro-apoptosis protein. BCL2 blocks apoptosis.
Del Re et al. (2019)	Human HeLa, BE2C and SH-SY5Y cells exposed to 900-MHz 217-Hz pulse-modulated RFR for 48 h; SAR 1 W/kg.	Increased transcription of repetitive DNA, type of transcription depended on cell type. (Alteration of repetitive DNA transcription can be induced by environmental stress conditions, causing human pathological effects.)	Repeated DNA sequences are important for cellular functioning and genome maintenance. Some are related to diseases such as Huntington's diseases.
Del Vecchio	Murine SN56 cholinergic cell line (48 and 72 h) and rat primary cortical	Increased expression of beta-thymosin (cytoskeleton regulating factor) m-RNA, and reduced neurite generation.	Beta-thymosin is an actin-sequestering protein in many cell types and a cytoskeleton regulating factor.

et al. (2009)	neurons (24, 72, 120 h) exposed to GSM-modulate 900 MHz RFR; SAR 1 W/kg.		
Ding et al. (2024)	RANKL-induced osteoclast differentiation in RAW264.7 cells exposed to 900 MHz CW RFR, 4 h/day for 5 days at 50, 150, or 450 μW/cm^2. (Osteoclasts involved in break down of bone tissue, and bone remodeling).	RFR decreased RANKL-induced NF-κB activation and suppressed the expression of downstream NF-κB target genes, such as NFATc1 and TRACP. Effect most effective at 150 μW/cm^2 (0.150 mW/cm^2).	Nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) is a family of transcription factor protein that controls transcription of DNA, cyto kine production and cell survival. NF-κB is involved in cellular responses to stimuli such as stress, cytokines, free radicals, heavy metals. It plays a key role in regulating the immune response to infection NFATc1 and TRACP are involved in osteoclast differentiation, increase osteoclast apoptosis and decreased osteoclast differentiation.
Ding et al (2022)	Mouse embryo Balb/c-3T3 cells exposed to 1800 MHz RFR; 4 h/day for 40 or 60 days at 8 W/kg.	Changes in gene expression, and induction of miRNA (malignant transformation of the cells observed; lipid metabolism was the pivotal biological process and pathway.)	Lipid metabolism was the pivotal biological process and pathway affected. Expression of 13 miRNA, including miRNA-124 involved in the microglial response to oxidative stress and miR-758 that is involved in inhibition of cell proliferation, migration, and invasion.
Eker et al. (2018) (LI)	Female Wistar albino rats exposed to 1800-MHz RFR for 2h/day for 8 weeks; SAR 0.06 W/kg.	Caspase-3 and p38MAPK gene expressions increased in eye tissues.	The CASP3 protein is a member of the cysteine-aspartic acid protease (caspase) family. Activated caspases plays a central role in the execution-phase of cell apoptosis. p38 mitogen-activated protein kinases are a class of mitogen-activated protein kinases (MAPKs) that are responsive to stress stimuli, such as heat shock, and osmotic shock, and are involved in cell differentiation, apoptosis and autophagy.

El-Kafoury et al. (2023)	Hippocampus of rats exposed to three GSM phones (850-1900 MHz) 2h/day, 6 days/week, for 12 weeks (50 missed calls/h, 35 sec durations separated by 15 sec. (No dosimetry data.)	Increased expression of Sirt1gene and Atg-7 gene. Effects reversed by lipoic acid, an antioxidant).	Sirt1gene encodes enzymes involved in cellular regulation, e.g., stressors, longevity. Atg-7 gene is involved in cell degeneration and recycling (autophagy).
Engelmann et al. (2008)	Cell suspension cultures of Arabidopsis thaliana exposed to 1900 MHz UMTS-modulated RFR for 24 h; SAR peak 2 W/kg, average 0.75 W/kg.	Significant changes in transcription of 10 genes.	Conclusion from the authors "…radiofrequency fields as used in UMTS-communication might be perceived by plants as irradiation, but are not recognized as a stress signal."
Ergan et al. (2025)	Rat model of muscle injury; 27.12 MHz RFR; 15 V/m, 180 min twice a day for 7 or 14 days.	RFR attenuate injury induced increases in TGFβ1 and eNOS gene expression in muscle.	TGF-β1 controls the immune system, and shows different activities on different types of cells, or cells at different developmental stages. eNOS involves in vasodilation, cellular proliferation, leukocyte adhesion, and platelet aggregation.
Franzellitti et al. (2008)	Human trohoblastes HTR-8/SVneo exposed to 1800 MHz continuous-wave, GSM-217-Hz, and GSM-Talk signals for 4-24 h, time averaged SAR 2 W/kg.	Levels of the inducible Hsp70C transcript were significantly enhanced after 24 h exposure to GSM-217 Hz signals and reduced after 4 and 16 h exposure to GSM-Talk signals. No effect on inducible Hsp70A, Hsp70B and the constitutive HSC70 transcripts.	Intracellularly localized Hsp70s are an important part of the cell's machinery for protein folding, performing chaperoning functions, and helping to protect cells from the adverse effects of physiological stresses. They inhibit apoptosis.
#Ghatei et al. (2017)	Mice exposed pre- and postnatally to radiation from a cellular phone jammer (900 and 1800 MHz).	At 8-10 weeks old, in the cerebellum, no effect on expression level of bcl-2 and p53 genes, but gene expression level of bax was decreased and gene expression level of p21 was increased.	BAX is a pro-apoptosis protein that affects the voltage-gated anion channels on mitochondrial membrane. p21 represents a major target of p53 activity and is associated with linking DNA damage to cell cycle arrest.

Gökçek-Saraç et al. (2021)	Hippocampus of rats exposed to UMTS 2100 MHz signal, 2 h/day for 7 days; 0.41 or 1.3 W/kg.	Decreased mRNA expressions of acetylcholinesterase, choline acetyltransferase and vesicular acetyl-choline transporter.	
Goswami et al. (1999)	Murine embryonic fibroblasts exposed to 835.62 MHz FMCW or 847.74 MHz CDMA RFR at 0.6 W/kg.	Increased proto-oncogene expression and Fos expression.	Proto-oncogenes code for proteins that help to regulate cell growth and differentiation. They can turn into oncogene by mutation. FOS is involved in cell proliferation, differentiation, survival, and in cancer development.
Gulati et al. (2020)	Human lymphocytes exposed to 3G mobile phone radiation (1923, 1947.47, and 1977 MHz); 1 or 3 h.	Inhibition of a bulk RNA expression and induction of DNA damage in dependence on UMTS frequency channel with maximal effect at 1977 MHz.	
*Gurisik et al. (2006)	Human cell lines (one of neuronal (SK-N-SH) and the other of monocytoid (U937) origin) exposed to a 900 MHz (217 Hz pulses) RFR for 2 h at 0.2 W/kg.	No effect on gene expression including Hsp70.	
Habauzit et al. (2014)	Human keratinocytes exposed to 60.4 GHz RFR for 3 h, incident power density of 20 mW/cm^2: SAR 594 W/kg (average), 1233 W/kg (peak).	7 gene expressions showed specific electromagnetic effect under hyperthermia condition (i.e., not mimicked by heat-shock controls).	Heat control did not mimic exactly the whole gene expression modification by mm-wave- 7 genes (ADAMTS6, NOG, IL7R, FADD, JUNB, SNAI2 and HIST1H1A) were significantly differentially expressed. Among them, 3 genes (ADAMTS6, NOG and IL7R) encode secreted factors that are specifically MMW-induced. Secreted proteins play important roles in the development of multicellular organisms, acting as structural matrix, extracellular enzymes, and signal molecules.

*Habauzit et al. (2020)	Male hairless ats exposed to 94 GHz RFR 3 h/day, 3 days/week for 5 months, incident power density 10 mW/cm2.	No significant modification of gene expression in skin cells.	
Hamann et al. (2006)	Rat sciatic nerve in mid-thigh, or to the L4 anterior primary ramus just distal to the intervertebral foramen exposed to 20 ms 500 KHz pulses at 2 Hz.	Up-regulation of transcription factor 3, ATF3, as an indicator of cellular "stress". (Effect appeared to be selective on neurons whose axons are the small diameter C and A delta nociceptive fibers.)	Cyclic AMP-dependent transcription factor ATF-3 is a transcription factor regulating gene expression.
Hao et al. (2022)	Rats exposed to 2856 MHz RFR for 15 min/day for 3 days, 10.5 W/kg; PC12 cells exposed to 2856 MHz RFR for 15 min, 19 W/kg.	Decreased expression of microRNA miR-30a-5p.	microRNA miR-30a-5p regulates genes involved in autophagy.
Harvey and French (1999)	Humen mast cell HMC-1 exposed to 864.3 MHz RFR for three 20 min/day for 7 days at 7 W/kg.	Up-regulation of proto-oncogene c-kit (KIT), the transcription factor nucleoside diphosphate kinase B (NDPK), the apoptosis-associated gene DAD-1, and some stress response genes.	Signaling through KIT plays a role in cell survival, proliferation, and differentiation. NDPK controls K^+ channels, G proteins, cell secretion, cellular energy production, and NDPK are involved in the synthesis of nucleoside triphosphates (NTP). DAD1, the defender against apoptotic cell death, is a negative regulator of apoptosis.
He et al. (2016) (LI)	Mouse bone marrow stromal cells exposed to 900 MHz RFR for 3 hours/day for 5 days at peak and average SARs of 4.1×10^{-4} and 2.5×10^{-4} W/kg.	Increased mRNA of poly(ADP-ribose) polymerase-1, a nuclear enzyme which plays an important role in the repair of damaged DNA.	
He et al. (2017) (LI)	Same as above and included \cells exposed to gamma radiation.	Increased mRNA of poly(ADP-ribose) polymerase-1, cells treated with RFR and gamma radiation showed less genetic damage and faster kinetics of repair.	Poly(ADP-ribose) polymerase 1 is involved in Differentiation, proliferation, and tumor transformation, recovery from

			DNA damage (repair of single strand DNA breaks), and induction of inflammation.
*Hirose et al. (2007)	Human glioblastoma A172 cells exposed to W-CDMA radiation at SARs of 0.08 and 0.8 W/kg for 2-48 h, and continuous-wave 2.1425 GHz RFR at 0.08 W/kg for 24 h, and human IMR-90 fibroblasts from fetal lungs were exposed to W-CDMA at 0.08 and 0.8 W/kg for 2 or 28 h, and continuous-wave at 0.08 mW/kg for 28 h.	No significant induction of phosphorylation of Hsp27 or expression of Hsp gene family.	The main function of Hsp27 is to provide thermotolerance *in vivo*, cyto-protection, and support of cell survival under stress conditions. inhibiting protein aggregation and by stabilizing partially denatured proteins. It has antiapoptotic properties and roles in cell growth (termination) and inflammatory and stress responses.
Huang et al. (2023)	Rat oligodendroglia exposed to CW or pulsed (50-Hz) 2400 MHz RFR for 6 or 48 h at SAR 0.23-0.8 W/kg (in medium of culture disk).	Change in expression of CCAAT/Enhancer-Binding Protein β (C/EBPβ) genes after pulsed RFR exposure (no effect with CW and on three other types of brain cells).	CCAAT/Enhancer-Binding Protein β (C/EBPβ) genes play a significant role in the development and function of nerve cells.
*Huang et al. (2008a)	Jurkat human T lymphoma cells exposed for 24 h to 1763 MHz RFR; SAR 10 W/kg.	Alterations in cell proliferation, cell cycle progression, DNA integrity or global gene expression were not detected.	
*Huang et al. (2008b)	HEI-OC1 immortalized mouse auditory hair cells exposed to 1763 MHz (CDMA) RFR for 24 or 48 h; SAR 20 W/kg.	No significant effects on cell cycle distribution, DNA damage, stress response, and gene expression.	
#Islam et al. (2023)	liver, brain and caecal tonsil samples taken from embryos in chick eggs	Vascular gene (VEGF-A) mRNA expression was higher, but immune gene (AvBD9 and IL6) expression was lower in the exposed group.	Vascular endothelial growth factor (VEGF) acts on endothelial cells and increased vascular permeability,

	exposed to 2100 MHz RFR from mobile phones for 60 min/day for 14 days.		inducing angiogenesis, vasculogenesis, and endothelial cell growth, promoting cell migration, and inhibiting apoptosis. Avian β-defensin9 (AvBD9) activates host-defense protein (HDP), an antimicrobial peptide.
Ivaschuk et al. (1997)	Rat PC12 pheochromocytoma cells treated with nerve growth factor exposed to 836.55 MHz TDMA signal for 20, 40, or 60 min at 0.00026, 0.0026 or 0.026 W/kg.	Decreased in c-jun gene expression at 0.026 W/kg after 20 min exposure (no effect at longer exposure duration); no effect on c-fos gene expression.	c-jun is an oncogenic transcription factor. It is required for progression through the G1 phase of the cell cycle. It has anti-apoptotic activity and is required for tumor cell survival between the initiation and progression stages.
Jeong et al. (2015)	Hippocampus of transgenic (Tg)-5xFAD mice exposed to 1950 MHz RFR 2 h/day, 5 day/week for 8 months, 5 W/kg.	5 genes (Tshz2, Gm12695, St3gal1, Isx and Tll1) involved in amyloid β were significantly altered. Effects not observed in normal mice.	
Jeong et al. (2020)	Hippocampus of two groups of C57BL/6 mice, aged 2 and 12 months, exposed to 1,950-MHz RFR 2 hr/day, 5 days/week for 8 months; 5 W/kg.	15 genes involved in neurogenesis, were altered in both groups; increased gene expression of Epha8 and Wnt6 in the hippocampi of the older group.	Epha8 plays a role in short-range contact-mediated axonal guidance during development of the mammalian nervous system. Wnt6 is involved in the formation and maturation of different embryonic structures, such as the fetal heart, ventral body wall, and somite derived structures.
Jin et al. (2021)	Murine melanoma cell line B16 and the human keratinocyte cell line HaCaT exposed to EMF-long term evolution radiation (LTE, 1.762 GHz) for 4 h at 8 W/kg; mice exposed to the radiation 8 h/day, 5	No effect on γ-H2AX (but p53 gene was up-regulated in cells; reduced the γ-H2AX level in the skin tissue of exposed mice.	p53 plays a role in the protective effect of EMF-LTE against DNA double strand breaks.

	day/week for 4 weeks, 6 W/kg.		
*Jooyan et al. (2023) (LI)	Chinese hamster ovary cells exposed to 900 MHz RFR (217-Hz modulation) for 24 h at 0.2-0.4 W/kg.	Increased single strand DNA breaks, no effect on micronuclear formation, No effect on COX-2 gene expression.	COX 2 is an enzyme involved in the production of prostaglandins (inflammatory messengers).
*Jyoti et al. (2025)	Human fibroblasts and keratinocytes exposed to 27 GHz or 40.5 GHz RFR for 2 or 48 h at 1 or 10 mW/cm^2.	No signicant effect on gene expression and DNA methylation. (There were an overexpression of the SULT1A4 gene and an underexpression of SULT1A3 in the same sample set. But effects considered to have no biological significance.)	
*Kao et al. (2013)	Db/db diabetic mice with wound exposed to pulsed 27.12 MHz RFR.	No effect on mRNA expression of vascular endothelial growth factor and basic fibroblast growth factor. However, wounds showed dermal cell proliferation and increased collagen synthesis.	
Karaca et al. (2012)	Mouse brain cells exposed to a 10.715 GHz RFR for 6 h/day for three days, SAR 0.725 W/kg.	Increased micronucleus, apoptosis and necrosis, and decreased expression of the STAT3 genes.	Signal transducer and activator of transcription 3 (STAT3) mediates the expression of a variety of genes in response to cell stimuli, and plays a key role in many cellular processes such as cell growth and apoptosis.
Khayat et al. (2023)	Pregnant rats exposed to 900 MHz RFR a 0.045μW/cm^2 12 h/days during pregnancy.	RFR acted synergistically with neonatal hypoxia-ischemia affecting brain MMP-9 and MMP-2 gene expression in male offspring.	MMP-9 and MMp-2 are collagenases involved in degradation of extracellular matrix in response to hypoxia.
Kim JH et al. (2021)	SH-SY5Y neuronal cells exposed to 1760 MHz RFR 4 h/day for 4 days; 4 W/kg.	Transcriptional activation of p53.	P53 activates DNA repair proteins in response to DNA damage, causes cell cycle arrest at the G1/S point, initiates apoptosis when DNA damage is irreparable.
Kim JH et al. (2024a)	Cerebral cortex of mice exposed to 1850 MHz RFR 5 h/day for 4 weeks at 4 W/kg.	Decreased expression of neuroligin2, neuroligin3, and neurexin1α genes.	Genes are involved in synaptic formation.

Kim JH et al. (2024b)	Mel-Ab melanocytes exposed to 1760 MHz RFR 4 h/day for 4 days; 4 W/kg.	Increased gene expression of melanocortin 1 receptor (MC1R) gene, no effect on expression of Hsp27, 70, 90 genes; increased melatonin content in cells.	Melanocortin 1 receptor (MC1R) reacts with melanocyte-stimulating hormone and affects melanin production in hair.
#Koohestanidehaghi et al. (2023)	Mouse preimplantation embryos exposed to 900-1800 MHz RFR from a cell phone or 30 min; 0.636-1.8 W/kg.	Increased Hsp70 and decreased superoxide dismutase (SOD) gene expressions and no effect on proapoptotic and antiapoptotic genes transcription.	Hsp70 stabilizes partially synthesized protein and prevents aggregation, protects cells from thermal and oxidative stress, disposal of damaged proteins, and inhibits apoptosis. SOD is an antioxidant enzyme.
Kucukbagriacik et al. (2022) (LI)	Liver and blood of mice exposed to 900 MHz GSM RFR; 4 h/day for 7 days; 0.339 W/kg.	Increased DNA repair mechanism genes expression (p53 and oxoguanine DNA glycosylase (OGG-1)).	P53 activates DNA repair proteins in response to DNA damage, causes cell cycle arrest at the G1/S point, initiates apoptosis when DNA damage is irreparable. 8-Oxoguanine glycosylase (OGG1) is involved in base excision repair.
Kundu et al. (2021)	40-day-old Swarnaprabha rice plants exposed to 1837.50 MHz RFR for 2.5 h at 2.75 mW/m^2.	Upregulation in calmodulin and phytochrome B gene expressions.	Calmodulin mediates many crucial processes such as inflammation, metabolism, apoptosis, smooth muscle contraction, intracellular movement, short-term and long-term memory, and the immune response involving calcium. Phytochromes control many aspects of plant development. They regulate the germination of seeds (photoblasty), the synthesis of chlorophyll, the elongation of seedlings, the size, shape and number and movement of leaves and the timing of flowering in adult plants.
*Kuribayashi et al. (2005)	Brain of rats exposed to 1439 MHz RFR, 90 min/day for 1 - 2 weeks, 2 or 6 W/kg.	No effect on expression of three blood-brain barrier-related genes (p-glycoprotein, claudin-5, and aquaporin-4). Increase in the mRNA expression of aquaporin-4 was observed in the young rats exposed at 6 W/kg for 1 week.	P-Glycoprotein is an ATP-dependent drug transport protein that is predominantly found in the membranes of a number of epithelial cell types. Absence of functional P-glycoprotein in the blood-brain barrier leads to highly increased permeability.

			At the blood-brain barrier, claudin-5 is the most enriched tight junction protein that limits diffusion of material between blood and brain. Aquaporin-4 in the blood-brain barrier is involved in its development and integrity.
Lai et al. (2023)	Rats exposed to 1500 MHz RFR (10.57 W/kg, 15 min) or EMP (400 pulses, 1 Hz, peak 11.65 kV/m) or combination of the two fields.	Increased mRNA expression of PTGS2 gene in hippocampus.	PTGS2 (COX-2) converts arachidonic acid (AA) to prostaglandin endoperoxide H2.
Lameth et al. (2020)	Healthy rats undergoing acute neuroinflammation triggered by a lipopolysaccharide (LPS) treatment, and transgenic hSOD1 rats that modeled a presymptomatic phase of human amyotrophic lateral sclerosis (ALS) exposed head only to a GSM-1800 MHz RFR for 2 h, SAR 1.21 or 3.22 W/kg.	Cortical cell gene modulations triggered by GSM-RFR in the course of an acute neuroinflammation and indicate that GSM-induced gene responses can differ according to pathologies affecting the CNS. At 1.21 W/kg, downregulation of Parvg, Akna, Fam107a, and Crlf1 genes were observed in the LPS-treated rats. No effect on healthy animals.	Parvg (Parvin Gamma) is a Protein Coding gene related to focal adhesion and Integrin-linked kinase signaling. Akna gene regulates inflammation and immune response. Fam107a is a stress-inducible actin-binding protein that plays a role in synaptic and cognitive functions. Crlf1gene encodes a member of the cytokine type I receptor family. The protein forms a complex with other cytokine factors that can promote the survival of neurons.
Lameth et al. (2025)	Rats head exposed to 3.5 GHz RFR, 1 h/day (5 days/week) for 6 weeks. Whole brain SAR 0.19 W/kg (antenna on right side: right cerebral hemisphere 0.43 W/kg, left hemisphere 0.14 W/kg).	Cells in entorhinal and piriform cortex showed up-regulation of genes related to glutamatergic synapses, and genes of the mitochondrial genome related to oxidative phosphorylation system. (More genes were activated in the left than the right hemisphere).	

*Lamkowski et al. (2018)	Human peripheral blood cells exposed to 900 MHz RFR for 30, 60, and 90 min; SAR 9.3 W/kg.	No significant effect on gene expression.	
*Lamkowski et al. (2021)	Human blood exposed to 900 MHz RFR for 30-90 min, 7-10 W/kg; experiment was repeated after 2 years with the same 5 human subjects.	Some changes in microRNA expression was detected in the first experiment, which was not replicated in the second experiment. 667 microRNA expressions were studied.	
Lawler et al. (2022)	Primary human dermal fibroblasts exposed to 60 GHz RFR, 2-4 days at 2.6 mW/cm^2, 46.8 J/cm^{-2} /day.	Genomic and transcriptomic alterations observed. Transcriptomic and genomic modifications are not associated with a typical cellular thermal or cytokine-induced response. They may be related to alteration in DNA secondary structures. Increase in COL1A1 gene expression.	COL1A1 gene encodes alpha-1 type I collagen, a protein that strengthens and supports many tissues in the body, including cartilage, bone, tendon, a nd skin. Collagenous function includes rigidity and elasticity.
Le Quément et al. (2012)	Primary human skin cells exposed to a 60.4-GHz RFR for 1, 6, or 24 h, SAR 42.4 W/kg.	Expression of 130 transcripts were found to be potentially modulated. PCR confirmed 5 genes (CRIP2, PLXND1, PTX3, SERPINF1, and $TRPV_2$) were differentially expressed after 6 h of exposure.	CRIP2 and the closely related CRIP1 are cysteine-rich proteins containing two LIM domains. They are highly expressed during cardiovascular development. Plexin-D1 is a cell surface receptor involves in cell-cell signaling and regulates the migration of various cell types, in synapse formation, and is required for normal heart and vasculature development. PTX3 activates the classical pathway of complement activation and facilitates pathogen recognition by macrophages. SERPINF1 has antiangiogenic, antitumorigenic, and neurotrophic properties. inhibit cancer cell proliferation and increase apoptosis. TRPV2 is a nonspecific cation channel. It has a structure similar to

			that of potassium channels, and has similar functions.
Lee K-S et al. (2008)	Drosophila exposed to 833 MHz RFR for 12 or 18 h, 1.6 or 4 W/kg.	1.6 W/kg activated an anti-apoptotic gene, whereas SAR 4.0 W/kg activated expression of apoptotic genes (JNK and ERK).	JNK1 is involved in apoptosis, neurodegeneration, cell differentiation and proliferation. Inflammation, reactive oxygen species, and a variety of stress stimuli can activate JNK. ERK (and related pathways) is involved in cell proliferation, differentiation, motility, and survival. ERK1/2 kinases also have pro-apoptotic functions and enhanced ERK1/2 signaling can cause tumor cell death.
Lee S et al. (2005)	HL-60 cells exposed to pulsed 2450 MHz RFR (155 μs, duty cycle 7.5%) for 2 or 6 h; 10 W/kg.	Number of gene expressions depended on exposure duration.	Apoptosis-related genes were among the upregulated ones and the cell cycle genes among the downregulated ones.
Li H et al. (2022)	PC12 cells and 293T cells exposed to 2856 MHz RFR, 5 min 3X at intervals of 5 min, 19 W/kg.	Transcriptional activity of 5-HT_{1A} receptor promoter containing rs198585630 C allele was higher than that of 5-HT_{1A} receptor promoter containing T allele (polymorphism). In vivo experiments with rats showed cognitive deficits and inhibition of brain electrical activity.	
Li J et al. (2025)	Human umbilical vein endothelial cells exposed to 2.52 THz RFR for 10 or 30 min at 100 mW/cm^2.	Increased expression of cytoskeleton-associated genes, including PDXP and SH3BP1. Also, increased angiogenesis capacity, angiogenesis-related proteins, and intracellular calcium. Effects attenuated by the calcium channel blocker diltiazem.	PDXP-involved in actin cytoskeleton and SH3BP1-involved in cell motility.
*Li Y et al. (2021)	Primary hippocampal neurons from C57BL/6 mice and Neuro2a cells exposed to 1,800 MHz RFR for 48 h; 4 W/kg.	Rap1 (Ras-related protein 1, a protein involved in cell proliferation and survival) activity was inhibited after 48 h of exposure with no detectable alteration in either gene or protein expression of Rap1.	

Li ZQ et al. (2020)	Pregnant rats exposed to 1800 + 2400 MHz or 2400 MHz RFR beginning on the 21st day of pregnancy; hippocampus of offspring examined at 7 weeks postnatal.	Altered mRNA expression of NMDA receptors. (Down and up-regulation dependent on the subtypes of receptor.)	NMDA receptors are involved in synaptic plasticity and learning and memory functions.
Lin et al. (2016) (LI)	Budding yeast exposed to 2000 MHz RFR for 96 h at 0.12 W/kg.	Upregulate the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not the glycolysis pathway.	
Lin et al. (2017)	Mouse Leydig (TM3) cells exposed to 1950 MHz GSM RFR for 24 h at 3 W/kg.	Decreased P450scc gene expression. (No effect on steroidogenic acute regulatory protein (StAR) expression.)	P450scc (scc- side chain cleavage)- a mitochondrial enzyme that conver ts cholesterol to pregnenolone- the first reaction in the production of various steroid hormones.
Lixia et al. (2006)	Human lens epithelial cells exposed to GSM-1.8 GHz RFR for 2 h, SAR 1, 2, 3 W/kg.	Increased mRNA and protein expression of Hsp70.	Hsp70 stabilizes partially synthesized protein and prevents aggregation, protects cells from thermal and oxidative stress, disposal of damaged proteins, and inhibits apoptosis.
Maalouf et al. (2023) (LI)	Adipose tissues of rats exposed to 900 MHz CW RFR; 1 h twice a day for 3 or 7 days at 0.1 or 0.4 W/kg.	Changed (increase and decrease) expression of genes involved in lipid, metabolism, energy homeostasis, and thermal regulation, and responsible for balancing the regulatory and damaging effects of reactive oxygen species. Different responses from white and brown adipose tissues. some effects were dose-dependent and time-dependent. Some effects occurred at 0.1 W/kg, but not at 0.4 W/kg.	
#Maluin et al. (2024)	Male reproduction parameter of rats exposed to radiation (2450 MHz) of Wi-Fi router (20 cm from rat) for 8 weeks; no dosimetry data.	Increased gene expression of estrogen receptor alpha (ERα); decreased expression of ERβ and C-KIT and SCF (stem cell factor) genes. C-KIT and SCF are involved in spermatogenesis.	ERα plays a role in the physiological development and function of a variety of including the reproductive, central nervous, skeletal, and cardiovascular systems. ERβ is a member of the nuclear receptor transcription factors. ERβ inhibits cell proliferation and opposes the actions of ERα in

			reproductive tissue and has an important role in adaptive function of the lung during pregnancy. ERβ is a potent tumor suppressor and plays a crucial role in many cancer types such as prostate cancer and ovarian cancer. KIT is a cytokine receptor expressed on the surface of hematopoietic stem cells as well as other cell types. It binds to stem cell factor (SCF) to form a dimer that activates tyrosine kinase and in turn phosphorylates and activates signal transduction molecules that propagate the signal in the cell. C-KIT and SCF are involved in spermatogenesis.
#Manta et al. (2017) (LI)	Four days-old adult female flies (Drosophila melanogaster) exposed to GSM-1800 talk mode RFR emitted by a commercial cellular phone for 30 min; SAR 0.15 W/kg.	168 genes were differentially expressed associated with multiple and critical biological processes, such as basic metabolism and cellular subroutines related to stress response and apoptotic death. Free radicals may be involved.	
Marinelli et al. (2004) (LI)	acute T-lymphoblastoid leukemia cells exposed to 900 MHz RFR for 2-48 h, SAR 0.0035 W/kg.	Increased DNA damage (DNA ladder) and activation of genes involved in pro-survival signaling (Bcl-2, Ras, Akt1).	Bcl-2 blocks apoptosis. Ras-regulated signal pathways is involved in actin cytoskeletal integrity, cell proliferation, cell differentiation, cell adhesion, apoptosis, and cell migration. Akt1 is a mediator of growth factor-induced neuronal survival and inhibitor of apoptosis.
Martin et al. (2020)	Four types of human keratinocytes exposed to 60 GHz RFR for 3 h at 594 W/kg.	With four keratinocyte cell types, three different gene expression (ADAMTS6, IL7R, NOG) patterns (downregulation, upregulation, and no effect) were	ADAMTS6 is involved in cardiovascular and musculoskeletal development.

		observed, despite their exposure having been the same in all regards.	Interleukin-7 receptor (IL7R) plays a critical role in the development of lymphocytes by blocking apoptosis. The NOG gene is related to the protein noggin which is involved in the development of many body tissues, including nerve tissue, muscles, and bones.
*Martin et al. (2024)	Keratinocytes (HEK and NHEK) and one keratinocyte derivate cell line (HaCaT) exposed 60.4 GHz RFR at 5, 10, 20 mW/cm^2 for 3 or 14 h.	No effect on gene expression. There were increases in HSPA1A/B (Hsp 70) and HSPB1 (Hsp27) expression similar to heating. RFR effects were considered to be due to heating.	
*McNamee et al. (2016)	Male C57BL/6 mice exposed to pulse-modulated or continuous-wave 1900 MHz RFR for 4 h/day for 5 consecutive days; whole body average SAR ~0.2 W/kg and ~1.4 W/kg.	No differentially expressed gene expressions were identified in various regions of the brain.	
Megha et al. (2015a) (LI)	Fischer rats exposed to 900 and 1800 MHz RFR for 30 days (2 h/day, 5 days/week), SAR 0.00059 and 0.00058 W/kg.	Reduced levels of neurotransmitters dopamine, norepinephrine, epinephrine, and serotonin, and downregulation of mRNA of tyrosine hydroxylase and tryptophan hydroxylase (synthesizing enzymes for the transmitters) in the hippocampus.	
Migdal et al. (2023) (LI)	Bees exposed to 900 MHz RFR for 0.25, 1, or 3 h at 0.05, 0.3, or 1.4 W/kg.	Increased expression of Hsp70 and Hsp 90 genes (at 0.05 W/kg for 3 h).	Hsp70s are an important part of the cell's machinery for protein folding. Hsp90 assists proper protein folding, stabilizes proteins against heat stress, and aids in protein degradation. It also stabilizes a number of proteins required for tumor growth.
Mildažienė et al. (2019)	Sunflower seeds exposed to 5.28	RFR exposure induced a long-term effect on gene expression in leaves, mostly stimulating expression of proteins	

	MHz RFR for 5, 10, 15 min, 12.7 kV/m.	involved in photosynthetic processes and their regulation.	
Nikolova et al. (2005)	Mouse embryonic neural progenitor stem cells exposed to 1710-MHz GSM RFR for 6 or 48 h; SAR 1.5 W/kg.	Exposure for 6 h, but not for 48 h, resulted in a low and transient increase of DNA double-strand breaks and down-regulation of neural-specific Nurr1 and in up-regulation of bax and GADD45 gene expression.	Nuclear receptor-related factor 1 (NURR1), a nuclear receptor superfamily of transcription factors, is a major risk factor in the pathogenesis of Parkinson's diseases. Bax is a pro-apoptosis protein. The Growth Arrest and DNA Damage or *gadd45* genes are stress sensors that modulate the response of mammalian cells to genotoxic/physiological stress, and modulate tumor formation. It can enable more efficient recognition and repair of spontaneous DNA damages generated by physiological processes and environmental factors.
Nylund and Leszczynski (2006)	Human endothelial cell lines EA.hy926 and EA.hy926v1 exposed to 900-MHz GSM RFR for 1 h; SAR 2.8 W/kg.	Gene and protein expressions were altered dependent on the cell type.	
#Obajuluwa et al. (2017)	Cerebral cortex of rats exposed to a Wi-Fi router (2500 MHZ, 11 v/m); 24 h/day for 4, 6, or 8 weeks.	Increased acetylcholinesterase (AChE) mRNA expression with decreased AChE activity.	
Ohtani et al. (2016)	Sprague-Dawley rats exposed to wideband code division multiple access 2140 MHz RFR for 6 h or 3 or 6 h/day for 4 days, SAR 4 or 0.4 W/kg.	Exposure at 4 W/kg (at 6 h/day) increased core temperature and upregulation of some stress markers, heat-shock proteins and heat-shock transcription factors family, in the cerebral cortex and cerebellum.	Heat-shock transcription factors regulate the expression of heat shock proteins. Its functions to overcome the proteotoxic effects of thermal stress, is needed for proper animal development, and the overall survival of cancer cells.
#Olejárová et al. (2022)	Human colon adenocarcinoma cell line DLD1 (CCL-221) cells exposed	Increased in cry1 mRNA expression; inhibitory effect of miR-34a (a tumor suppressor) on per2 and survivin was weakened and abolished, respectively.	cry1is a mammalian circadian photoreceptor. per2 protein is involved in circadian rhythms.

	to 2426-2448 MHz Wi-Fi signal; 2.79 ms 9.7 Hz pulses 19V/m peak 6.6 V/m RMS, for 24 h.		Survivin is an inhibitor of apoptosis.
Ozden et al. (2025)	Blood from terminal ileum of rats subjected to mesenteric artery ischemia and exposed to 27.12 MHz RFR before or after ischemia; 30 min at 10 V/m.	Ischemia-induced increased gene exposure of VEGF, BAX, and HIF1α and decreased gene expression of BCl-2 and eNOs attenuated by RFR.	Vascular endothelial growth factor (VEGF) acts on endothelial cells and increased vascular permeability, inducing angiogenesis, vasculogene sis, and endothelial cell growth, promoting cell migration, and inhibiting apoptosis. Bax is a pro-apoptosis protein. The transcription factor HIF-1 (Hypoxia-inducible factor 1-alpha) plays an important role in cellular response to systemic oxygen levels in mammals. Overexpression of *HIF1A* is implicated in the pathology of vascularization and angiogenesi s, energy metabolism, cell survival, and tumor invasion. BCL2 blocks apoptosis. eNOS enzyme for nitric oxide synthesis.
Pacini et al. (2002)	Human skin fibroblasts exposed to GSM 904.2- MHz RFR for 1 h (from a cell phone); SAR 0.6 W/kg.	Increased the expression of mitogenic signal transduction genes (e.g., MAP kinase 3, G2/mitotic-specific cyclin G1), cell growth inhibitors (e.g., transforming growth factor-beta), and genes controlling apoptosis (e.g., BAX).	
*Paparini et al. (2008)	Mice exposed to GSM 1800-MHz signal for 1 h; SAR whole body average 1.1 W/kg, brain 0.2 W/kg.	No significant modulation in gene expression in whole brain.	
Park et al. (2018)	HT22 mouse hippocampal neuronal cells and SH-SY5Y cells exposed to 1950	mRNA levels of APP, BACE1, ADAM10 and PSEN1 were decreased in HT22 cells. SH-SY5Y cells had similar effects except APP mRNA showed no change.	Amyloid-beta precursor protein (APP) is an integral membrane protein expressed in in the synapses of neurons. It is involved in synapse formation and neural plasticity,· it is the

	MHz RFR 2 h/day for 3 days at 6 W/kg.		precursor molecule of amyloid beta (Aβ). BACE1, ADAM10 and PSEN1 are secretase enzymes that process APP and formation of Aβ.
Piccinetti et al. (2018) (LI)	Zebrafish embryos exposed to 100 MHz RFR from immediately after fertilization to 72 h post-fertilization, SAR about three orders of magnitude lower than ICNIRP basic restrictions of 0.08 W/kg.	At the 48 h post-fertilization stage- an increased transcription of oxidative stress genes and reduced growth.	
Pooam etal. (2022)	Human HEK293 cells exposed to 1800 MHz RFR for 15 min. (no dosimetry data.)	Increased gene expression of antioxidant enzymes (SOD, GPx, CAT).	
Porcher et al. (2023) (LI)	Leaves of Arabidopsis thaliana exposed to 2450 MHz RFR for 30 min at 0.21 W/kg.	Increased accumulation of transcripts of stress-related genes (TCH1 and ZAT12 transcription factor) and genes involved in ROS metabolism (RBOHF and APX1).	Zat12 plays a central role in reactive oxygen and abiotic stress signaling in Arabidopsis. RBOHF regulates biotic and abiotic stress tolerance and developmental processes. APX1 has the role of scavenging reactive oxygen species for protection against oxidative damage and maintaining normal plant growth and development.
*Porcher et al. (2024) (LI)	Arabidopsis thaliana (thale cress weed) grew on petri dish to approx. 1 cm; exposed to 30,000 EMF pulses (50 Hz, (237 kV m-1 , 280 ps rise-time, duration of 500 ps) carrier frequency < 2000 MHz; SAR 10^{-13} to 10^{-16} W/kg.	No effect on mRNA levels of calmodulin, Zinc-Finger protein ZAT12, NADPH oxidase/respiratory burst oxidase homolog (RBOH) isoforms D and F, Catalase (CAT2), glutamate-cystein ligase (GSH1), glutathione synthetase (GSH2), Sucrose non-fermenting-related Kinase 1 (SnRK1) and Target of rapamycin (TOR).	

*Port et al. (2003)	Human leukaemia cells (HL-60) exposed to pulsed (1 Hz) 400 MHz RFR for 6 min;50 kV/m- 25 times higher than the ICNIRP reference levels for occupational exposure.	No significant effects on apoptosis, micronucleation, abnormal morphologies, and gene expression (1176 genes) assayed at 9, 24, 48, and 72 h post-exposure.	
Pyrpasopoulou et al. (2004) (LI)	Kidney of offspring of rats exposed to 9400 MHz RFR on 1-7 post-coitum days at 0.0005 W/kg.	Increased bone morphogenetic proteins (BMP-4) and their receptors (BMPR-IA), and decreased BMPR-II gene expressions.	Bone morphogenetic protein receptor type II (BMPR2) is involved in a host of cellular functions including osteogenesis, cell growth, and cell differentiation.
Qin et al. (2014) (LI)	Rats exposed to 1800 MHz RFR for 2 h/day for 32 days at 0.0405 W/kg.	Altered mRNA expression of cytochrome P450 and steroidogenic acute regulatory protein.	
Qin et al. (2019) (LI)	Mouse Leydig cells exposed to 1800 MHz RFR; 1, 2, or 4 h; 0.116 W/kg.	Down-regulation of testosterone synthase genes and clock genes.	
Qin et al. (2021)	Testis of four-week-old mice exposed to 1800 MHz RFR, 1 h at 7 am and another hour at 7 pm each day for 21 days; 0.50 W/kg.	Expression of non-coding RNAs play crucial roles in the RFR exposure damage to the developing pubertal testis.	
*Qutob et al. (2006)	Human U87MG glioblastoma cells exposed to pulse-modulated 1900 MHz RFR for 4 h; SAR 0.1, 1.0, and10 W/kg.	No significant effect on gene expression.	
*Regalbuto et al. (2020)	Human fibroblasts exposed to continuous or pulsed 2450 MHz RFR for 2 h, 0.7 W/kg.	No effect on gene expression profile.	

Remondini et al. (2006)	Six human cell types exposed to 900 and 1800 MHz RFR; three exposure systems were used, exposure time 1, 24, or 44 h, SAR 1 - 2.5 W/kg. (Details in Table 1 of paper.)	Some but not all human cells reacted to RFR with an increase in expression of genes encoding ribosomal proteins and therefore up-regulating the cellular metabolism.	
Romano-Spica et al. (2000)	Jurkat T-lymphoblastoid and Leydig TM3 cells exposed to 50 MHz 16-Hz modulated (a calcium resonance frequency) RFR for 0.5 - 6 h at 60 V/m.	overexpression of the ets1 mRNA (a transcription factor). No effect with non-modulated field.	Ets1 binds to DNA and is expressed mainly in immune tissues such as thymus, spleen, and lymph node (B cells, T cells, NK cells, NK T cells and non-lymphoid immune cells). Expression of Ets1 blocks differentiation of B- and T-cells.
Roux et al. (2006)	Tomato plants exposed to a 900-MHz RFR, 2-10 min, 5-40 V/m.	Stress-related transcripts (calmodulin, protease inhibitor and chloroplast mRNA-binding protein) increased 15 min after the end of exposure (10 min), dropped to close to initial levels by 30 min, and then increased again at 60 min.	
Roux et al. (2008)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2.	Induction of stress gene expression; similar to wound responses suggesting that the radiation is perceived by plants as an injurious stimulus.	
*Roux et al. (2011)	Human keratinocytes exposed to 900 MHz RFR for 10 or 30 min at 0.0026 - 0.073 W/kg.	No effect on gene expression (47000 human genes).	
Said-Salman et al. (2019)	Escherichia coli K-12 DH5α exposed to 2.4 GHz RFR for 5 h.	Expression of 101 genes were differentially affects (up- and down-regulation).	Up-regulated genes are involved in metabolic pathways, transposition, response to stimuli, motility, chemotaxis and cell adhesion. The down-regulated genes are associated with metabolic pathways and localization of ions and organic molecules.
#Saka et al. (2023)	Primary cortical neurons from neonatal rat cerebral	Increased expression of Bax and p53 genes, decreased expression of Bcl2 gene.	BAX is a pro-apoptosis protein. Tumor protein p53 conserves stability by preventing genome

	cortex exposed to 2100 MHz RFR for 2 h at 1.6 W/kg.		mutation, and prevents cancer development. BCL2 blocks apoptosis.
*Sakurai et al. (2011)	Human glial cell line, SVGp12, exposed to continuous-wave 2450 MHz RFR for 1, 4, and 24 h; SAR 1, 5, and 10 W/kg.	No effect on gene expression.	
Salameh et al. (2022)	Liver of rats exposed pre-and postnatally (24 h/day) to GSM 900 MHz RFR; 0.783 W/kg at liver.	Reduction (PND1 and PND9) in catalase amounts and mRNA expression, SOD1 mRNA expression increased at PND1, and decreased at PND9 and 21.	
Salameh et al. (2022)	Liver of rat embryos exposed 24 h/day to 7.5, 11.5, 15.5, or 19.5 days post coitus to 900 MHz GM RFR; 0.783 W/kg at liver.	Decreased expression of catalase and intercellular adhesion molecule-1 (ICAM-1) RNA.	ICAM-1is a type of intercellular adhesion molecule in the membranes of leukocytes and endothelial cells. ICAM-1 can be induced by interleukin-1 (IL-1) and tumor necrosis factor (TNF) When activated, leukocytes bind to endothelial cells via ICAM-1/LFA-1 and then transmigrate into tissues.
*Sannino et al. (2024b)	SH-SY5Y human neuroblastoma cells to 1950 MHz, UMTS signal; 20, 10, 3 or 1 h/day for 3 days, 0.3 0or 1.5 W/kg; followed by menadione injection.	RFR had no effect on DNA single strand breaks, but attenuated breaks induced by menadione. RFR had no effect on thioredoxin-1, heat shock transcription factor 1, heat shock protein 70, and poly [ADP-ribose] polymerase 1 expression (molecules involved on cellular stress response).	
*Savchenko et al. (2023)	Mice exposed to 915 MHz RFR 9 h/day for 14 days at 40 W/kg.	No effects on gene expressions of BAX, BCL-2, SOD2, CAT, collagen III, and TGF β-1.	
Seewooruttun et al. (2025) (LI)	Adipose tissue from rats exposed to 3.5 GHz (0.07 W/kg) ot 900 MHz (0.24 W/kg) RFR; I h/day for 1 or 2 weeks.	Decreased in adipogenic biomarker gene expression- PRDM16 and C/EBPβ.	Both genes are involved in the proliferation and differentiation of mature brown adipocytes from precursors. (Brown adipose tissue hyperplasia is also crucial for

			adapting to cold-inducible environments.)
*Sekijima et al. (2010)	Human A172 (glioblastoma), H4 (neuroglioma), and IMR-90 (fibroblasts from normal fetal lung) cells exposed to continuous- wave and W-CDMA 2.1425 GHz RFR up to 96 h; SAR 0.08, 0.25, 0.8 W/kg	No significant effects on gene expression and cell proliferation.	
Shang et al. (2024)	Caenorhabditis elegans exposed to 0.262 THz RFR at 24 mW/cm^2 for 5 min.	Down regulation of cuticle collagen genes, immune response genes, and neurogenesis and nervous system development genes.	
Šofranková et al. (2023)	Synganglion of Ixodes Ricinus (tick) exposed to 900 MHz RFR at 2 or 4 V/m for 10 min, 1, 3, or 24 h.	Decreased expression of neuropeptide genes (allatotropin (at), FGLa-related allatostatins (fgla/ast), kinin, and arginine-vasopressin-like peptide (avpl)); responses are exposure-duration-dependent; male and female ticks responded differently.	
Šofranková et al (2024)	Synganglion of Ixodes Ricinus (tick) exposed to 900 MHz RFR at 2 or 40 V/m for 10 min, 1, 3, or 24 h.	Changes in expression of neuropeptides SIFamide and myoinhibitory peptide (mip and sifa) genes (involved in growth, development, behavior and reproduction in insects); effects depended on time and intensity of exposure and sex of the tick. Expression of receptors of these peptides were also affected.	
Son et al. (2023)	Hippocampus of 5xFAD mice (mouse model of Alzheimer's disease) exposed to 1950 MHz RFR, 2 h/day. 5 days/week for 6 months at 5 W/kg.	Decreased expression of genes related to microgliosis and microglial functions, and interleukin-1β.	Interleukin-1β is a cytokine that mediates inflammatory response, and is involved in a variety of cellular activities, including cell proliferation, differentiation, and apoptosis.
Soubere Mahamoud et al. (2016)	Human keratinocyte exposed to a 60.4-GHz RFR at an incident power	No keratinocyte transcriptome modifications were observed. Co-treatment with a glycolysis inhibitor slightly alters the transcriptome of 6	

	density of 20 mW/cm^2 for 3 h.	genes encoding transcription factors or inhibitors of cytokine pathways. Thus, RFR exposure may affect metabolically stressed cells.	
#Souza et al. (2014)	Exfoliated cells from the oral epithelium from human subjects who spent different time using cell phones (group I, $t > 5$ h; group II, $t > 1$ h and ≤ 5 h; and group III, $t \leq 1$ h).	Structures that may be associated with gene amplification were significantly greater in the individuals in group I. No significant effects on micronucleus frequency and apoptosis and necrosis were observed.	
Sueiro-Benavides et al. (2023)	HL-60 cells exposed to 2450 MHz RFR for 8, 24, or 48 h, 0.406 W/kg.	Increased FAS-R gene (related to apoptosis) expression after 24 and 48 h exposure. Interacted with black carbon particles.	The FAS receptor is on the surface of cells that leads to apoptosis if it binds its ligand.
Sun L. et al. (2025) (GE)	Blood of rats exposed to 2800 and/or 9300 MHz RFR, 6 min at 10 mW/cm^2.	Increased Htt and Bdnf gene expression. (Huntingtin (Htt) is the protein coded for in humans by the HTT gene. Mutated HTT is the cause of Huntington's disease. It also is involved in long-term memory storage. BDNF (Brain-derived neurotrophic factor) acts on certain neurons of the central and peripheral nervous system, helping to support survival of existing neurons, and encouraging growth and differentiation of new neurons and synapses.)	
Suzuki et al. (2025)	Arabidopsis thaliana exposed to 2450 MHz RFR for 1 h. no dosimetry data.	Changed expression of genes involved in altered circadian clock as well as hormonal response especially in auxin and gibberellin, which promoted plant growth by inducing amino acid biosynthesis and stress tolerance, and reducing cell wall thickness. Pattern different from heating. Induced by pulsed but not continuous-wave RFR.	
Tarsaei et al. (2022)	Hippocampus of rats exposed to 2450 MHz RFR for 7 or 30 days, at 4 mW/cm^2.	Increased Bax (Bcl2-associated) and reduced Bcl-2 (B-cell lymphoma 2) genes expression. (Genes are related to apoptosis.)	Increase apoptosis.

#Tohidi et al. (2021)	Hippocampus of mice exposed to RFR from a mobile phone jammer with 4 bands (900 MHz, 1800 MHz, CDMA and GSM) for 0.5, 1, 2, or 4 h twice a day for 30 days, or 4 h/day for 30 days.	Expression of both *Bax* and *Bcl2* genes (related to apoptosis) were upregulated in mice exposed for one and two hours, and downregulated in animals with longer exposure.	
#Tran et al. (2023)	Lettuce plants (Lactuca sativa) exposed to 1800-1900 MHz (0.0008 mW/cm^2) and 2450 and 5000 MHz RFR (0.0002 mW/cm^2) from DECT base station and phones for 2-6 weeks.	Down-regulation of two stress-related genes of violaxanthin de-epoxidase and zeaxanthin epoxidase.	
Tsuji et al. (2025)	Lysposomes exposed to pulsed 460-GHz RFR for 1 or 3 h; no dosimetry data.	The intraliposomal transcription reaction was inhibited during irradiation, regardless of the energy per pulse.	
Tuysuz et al. (2025)	Astrocyte-derived U118-MG cells exposed to 2100 MHz RFR for 1, 24, or 48 h at 1.12 W/kg.	increased Casp3, Casp8, and Casp9 mRNA after 24 or 48 h exposure. (Apoptosis after 48 h exposure with an increase in BAX/BCL-2 ratio, that initiates apoptosis.)	Caspase-3 is a caspase protein that plays an important role in apoptosis. It interacts with caspase-8 and caspase-9. It is the predominant caspase involved in the cleavage of amyloid-beta 4A precursor protein,
Üstündağ et al. (2020)	Zebrafish embryos exposed to 3000 MHz RFR. (No dosimetry data.)	Decreased tp53 and increased Casp3a gene expression.	TP53 gene encodes proteins that bind to DNA and regulate gene expression to prevent mutations of the genome.
#Vafaei et al. (2020) (LI)	Placenta of pregnant mice exposed to 2.4 GHz RFR from a D-link Wi-Fi router; 2 or 4 h/day at 30 or 60 cm from router from 5 days after mating to 1 day before expected	Increased gene expression of SOD, and GDKN1A, and GADD45a (DNA repair enzymes).	CDKN1A functions as a regulator of cell cycle progression at G1. CDKN1A plays a critical role in the cellular response to DNA damage. The GADD45 genes transcript levels are increased following stressful growth arrest conditions and treatment with DNA-damaging agents, mediating cell cycle arrest

	delivery, 0.09 W/kg at 30 cm.		at G2/M phase and inducing apoptosis.
*Valbonesi et al. (2008)	Human trophoblast cell line HTR-8/SVneo exposed to pulsed 1817 MHz RFR for 1 h; SAR 2 W/kg.	No significant change in either Hsp70 or Hsc70 protein or gene expression, or DNA single strand breaks.	HSC70 plays a role in protein folding, signal transduction, apoptosis, protein homeostasis, and cell growth and differentiation. It is involved in chaperone-mediated autophagy by aiding the unfolding and translocation of substrate proteins across the membrane into the lysosomal lumen. Unlike HspSP70, Hsc70 is constitutively expressed and performs functions related to normal cellular processes, such as protein degradation.
Valbonesi et al. (2014)	Rat PC12 cells exposed to continuous-wave 1.8 GHz RFR or GSM-217 Hz and GSM-Talk signals for 4, 6, or24 h, SAR 2 W/kg.	After PC12 cells exposure to the GSM-217 Hz signal for 16 or 24 h, Hsp70 mRNA transcription significantly increased, whereas no effect was observed in cells exposed to the CW or GSM-Talk signals.	Hsp70 stabilizes partially synthesized protein and prevents aggregation, protects cells from thermal and oxidative stress, disposal of damaged proteins, and inhibits apoptosis.
*Valbonesi et al. (2016)	Rat PC12 cells exposed to 1.8 GHz 217-GSM signal for 24 h. SAR 2 W/kg.	AChE transcriptional or translational pathways not affected, whereas AChE enzymatic activity increased.	
Verma and Dutta (1993) (LI)	pNGE7 cells exposed to 16-Hz modulated 915 MHz RFR at 0.00005 W/kg.	Altered expression of neuron specific enolase gene.	Enolase catalyzes the conversion of 2-phosphoglycerate (2-PG) to phosphoenolpyruvate (PEP) in glycolysis.
Vian et al. (2006)	Tomato plants exposed to a 900-MHz RFR for 10 min at 0.0066 mW/cm^2.	Induction of mRNA encoding the stress-related bZIP transcription factor (3.5 folds at 5-15 min post-exposure).	The bZIP gene family plays important roles in growth and development, maturation of flowers, and stress responses in plants.
Wang D. et al. (2023)	Leaves of *Pinellia ternata* exposed to THz waves (no exposure parameter data available).	Expression of 1,695 genes affected, including 509 upregulated and 1,186 downregulated genes.	
Wang Y et al.	Drosophila melanogaster	In third-instar larvae, expression levels of the heat shock protein genes Hsp22,	Translocation of both Hsp22 and iNOS to the mitochondria is

(2022) (LI)	exposed to 3.5 GHz RFR for 2-3 days at 0.0026 W/kg, 0.026 W/kg, or 0.26 W/kg.	Hsp26 and Hsp70 and humoral immune system genes AttC, TotC and TotA were all significantly increased.	necessary for Hsp22-mediated stimulation of oxidative phosphorylation. Hsp26 binds and prevents unfolded proteins from forming aggregates. Hsp70 stabilizes partially synthesized protein and prevents aggregation, protects cells from thermal and oxidative stress, disposal of damaged proteins, and inhibits apoptosis. Attc involves in gene transfer. TOTC gene provides instructions for making the enzyme ornithine transcarbamylase. This enzyme participates in the urea cycle, a series of reactions that occurs in liver cells. The Drosophila Turandot A (TotA**)** gene was recently shown to encode a stress-induced humoral factor which gives increased resistance to the lethal effects of high temperature.
*Whitehead et al. (2005)	Murine embryonic fibroblasts exposed to 835.62 MHz FMCW, 847.74 MHz CDMA, or 836.55 MHz TDMA RFR at 5 or 10 W/kg.	No effect on Fos proto-oncogene expression.	Fos is involved in cell proliferation, differentiation and survival, associated with hypoxia and angiogenesis.
*Whitehead et al. (2006a)	Murine embryonic fibroblasts exposed to 835.62 MHz FMCW, 847.74 MHz CDMA RFR for 24 h at 5 W/kg.	No statistically significant effect on gene expression.	
*Whitehead et al. (2006b)	Murine embryonic fibroblasts exposed to 835.62 MHz FMCW, 847.74 MHz CDMA RFR for 24 h at 5 W/kg.	No statistically significant effect on gene expression (Gapd, Fos, Jun, Rasa3, Hsp).	GAPDH acts as a reversible metabolic switch to glycolysis under oxidative stress. Fos is involved in cell proliferation, differentiation and survival and associated with hypoxia and angiogenesis.

			Jun regulates gene expressions involved in cell growth, differentiation, and neoplastic transformation. Rasa3 is a member of the GAP1 family of GTPase-activating proteins involved in the control of cellular proliferation and differentiation.
Wu H et al. (2012)	At Sertoli cells exposed to s-band microwaves for 4 min at 100 mW/cm^2.	Upregulation of Bax/Bcl-2 and caspase-3 genes.	Increase apoptosis.
Xu et al. (2010)	Sprague-Dawley rat primary cultured cortical neurons exposed to intermittent (5 min ON/10 min OFF) 217-Hz triangularly pulsed 1800 MHz RFR for 24 h; SAR 2 W/kg.	Increased in the levels of 8-hydroxyguanine, in the mitochondria of neurons, levels of mitochondrial RNA (mtRNA) transcripts showed a reduction. Effects are attenuated by melatonin.	
Xue et al. (2024)	Brain (hippocampus, thalamus, and cerebrum) of rats exposed to dual frequency 2650/800 MHz RFR (each frequency for 2 h for 21 days); SAR 4 W/kg.	A decrease in the expression of Cnr1, encoding cannabinoid receptor 1 Type (CB1R) gene, only in the cerebrum.	CB1-receptors are brain development, learning and memory, motor behavior, regulation of appetite, body temperature, pain perception, and inflammation.
#Yan et al. (2007)	Sperm from rats exposed to RFR from a PCS CDMA (1900 MHz) mobile phone; two 3 h periods per day for 18 weeks.	Increased mRNA of cell surface adhesion proteins CAD-1 and ICAM-1.	
#Yan et al. (2008)	Adult Sprague-Dawley rats exposed to a cell phone 1.9 GHz (PCE CDMA) for 6 h per day for	Significant mRNA up-regulation of injury-related proteins in the brain of rats exposed to cell phone radiation.	Calcium ATPase, Neural Cell Adhesion Molecule, Neural Growth Factor, and Vascular Endothelial Growth Factor were evaluated.

	126 days (18 weeks).		
Yang et al. (2012)	Hippocampus of rats exposed to 2450 MHz RFR for 20 min at 6 W/kg.	23 upregulated and 18 downregulated genes were identified including Hsp27 and Hsp70 genes.	The main function of Hsp27 is to provide thermotolerance *in vivo*, cytoprotection, and support of cell survival under stress conditions. inhibiting protein aggregation and by stabilizing partially denatured proteins. It has anti-apoptotic properties and roles in cell growth (termination) and inflammatory and stress responses. Hsp70 stabilizes partially synthesized protein and prevents aggregation, protects cells from thermal and oxidative stress, disposal of damaged proteins, and inhibits apoptosis.
Yao et al. (2025)	Testis of rats exposed to 2856 MHz RFR, 15 min/day, 5 day/week for 6 weeks; whole body SAR 9 W/kg; testis 19.8 W/kg; body temperature increase 0.83ºC.	Up-regulation of Cebpb, Gpx5, and CFTR.	Cebpb encodes the important transcription factor CCAAT/enhancer binding protein β (C/EBPβ), which is Involved in DNA binding and in the nervous system in neuronal differentiation, learning, and memory processes, in glial and neuronal cell functions, and in neurotrophic factor expression. Gpx5 is related to oxidative stress and spermatogenesis, and CFTR is a potential target for post-meiotic fertility regulation.
Yavas et al. (2024) (LI)	Brain and testis of exposed rats; 2100 MHz RFR; 5 h/day for 14 days; 10 g and 1 g SAR (W/kg)- brain 0.292 and 0.578; testes 0.163 and 0.316.	Brain- decreased Bax (pro-apoptosis), increased Bcl-2 (apoptosis blocker), no effect on p52 gene expressions; increased double strand DNA breaks. Testes- decreased Bax gene expression.	Increase apoptosis.
Yu et al. (2023)	Rats exposed scrotally to 2605 MHz RFR, 6/hr per day for 50, 100, or	mRNA level of testicular androgen receptors increased in 50 day-exposed and decreased in 150 day-exposed group.	

	150 days, 1.05 W/kg.		
#Zalata et al. (2015)	Human semen samples exposed to 850-MHz RFR from a cell phone for 1 h; SAR 1.46 W/kg at 10 cm.	Significant increase in sperm DNA fragmentation percent, clusterin gene expression and clusterin protein (associated with clearance of cellular debris and apoptosis) levels in the exposed semen samples.	Clusterin is an extracellular molecular chaperone which binds to misfolded proteins in body fluids to neutralize their toxicity and mediate their cellular uptake by receptor-mediated endocytosis and transfer into lysosomes for degradation.
Zhang M et al. (2025)	Liver of mice exposed to 2450 MHz RFR for 6-8 min at 15 W/kg.	Changes in expression of Bhmt, Acat2, Cyp2e1, Akr1c6, Hmgcs2, and Pck1 genes.	Betaine homocysteine S-methyltransferase (Bhmt) converts homocysteine to methionine. *ACAT2* (acetyl-Coenzyme A acetyltransferase 2) is involved in cholesterol synthesis and ketone body metabolism. The CYP2E1 gene encodes an enzyme that plays a crucial role in the metabolism of various substances, including drugs and toxins, and is significantly involved in alcohol metabolism. Akr1c6 (aldo-keto reductase family 1, member C6) Involved in steroid biosynthetic process. Hmgcs2 (3-hydroxy-3-methylglutaryl-CoA synthase 2 (mitochondrial)) that catalyzes the second and rate-limiting reaction of ketogenesis, a metabolic pathway that provides lipid-derived energy for various organs. PCK1 (Phosphoenolpyruvate carboxykinase 1) is involved in gluconeogenesis that generates glucose from non-carbohydrate substrates.
Zhang SZ et al. (2008)	Primary culture of rat neurons exposed to a 1800 MHz RFR for 24 h; SAR 2 W/kg.	Changes (down-regulation of Egr-1 and up-regulation of Mbp, Plp) of many gene transcriptions (involving cytoskeleton, signal transduction pathway, metabolism, etc.) were observed.	EGR-1 (Early growth response protein 1) is a transcriptional regulator. The products of target genes it activates are required for differentiation and mitogenesis. It is a tumor suppressor gene. it has a

			role in neuronal plasticity, and learning and memory functions. Myelin basic protein (MBP) is a protein involves in myelination of nerves. Proteolipid protein 1 (Plp) is a transmembrane proteolipid protein that is the predominant myelin protein present in the central nervous system.
Zhao L et al. (2022)	Rats exposed to 1500 MHz, 4300 MHz, or combination of the two RFRs at 10 mw/cm^2.	Observed immune suppressive responses via regulating immune regulation and cellular metabolism-associated genes (noted in lymphocytes and spleen).	In the peripheral blood, down-regulated genes are involved in positive regulation of cytotoxic T cell differentiation, T-helper cell differentiation and immunoglobulin production, whereas up-regulated genes participated in negative regulation of macrophage activation. In the spleen, up-regulated genes are involved in B cell affinity maturation and the B cell receptor signaling pathway and negative regulation of T cell proliferation. The down-regulated genes sparticipat inTh17 cell differentiation and the IL-17 signaling pathway, suggesting that the functions of T lymphocytes are inhibited.
Zhao R. et al. (2007)	Rat neurons exposed to pulsed 217-Hz modulated 1800 MHz RFR for 24 h; SAR 2 W/kg.	up- and down-regulation of genes transcriptions were observed.	"RF exposure might alter the skeleton of cells and CNS by activating some signal transduction pathways, thus led to abnormal neural growth and metabolism."
#Zhao TY. et al. (2007)	Primary cultured neurons and astrocytes exposed to a GSM 1900 MHz cell phone for 2 h.	Up-regulation of caspase-2, caspase-6 and Asc (apoptosis associated speck-like protein containing a card) gene expression in neurons and astrocytes. Additionally, astrocytes showed up-regulation of the Bax gene. Neurons appeared to be more sensitive to this effect than astrocytes.	In addition to apoptotic role, caspase-2 also contributes to maintaining genomic stability and responding to cellular stress. Caspase-6 plays a central role in the execution-phase of cell apoptosis, reduces the expression of the immunosuppressant cytokine interleukin-10, cleaves HTT in Huntington's and A

			PP in Alzheimer's disease, resulting in protein aggregation. Asc is involved in the inflammatory and apoptotic signaling pathways via the activation of caspase.

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