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Radiofrequency Radiation Low-Intensity Studies

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This is a summary of the literature on the biological effects of low-intensity RFR (SAR < 0.4 W/kg) exposure. There are 260 studies that reported effects included in the analysis. The SARs can be considered as the average SARs of the exposed objects (i.e., animal or cell culture). Most of the studies were carried out with RFR of <2500 MHz. There are several studies with millimeter waves. Studies can be segregated into *in vivo* vs *in vitro* experiment and acute (one time) vs repeated/chronic exposure.

	Acute exposure	Repeated/chronic exposure	
In vivo	**32**	**174**	**206 (79%)**
In vitro	**45**	**9**	**54 (21%)**
	77 (30%)	**183(70%)**	**260**

1. **Most of the studies are in vivo chronic exposure experiments. Thus, the results are more applicable in the assessment of real life RFR exposure in the environment.**
2. **There are many different biological endpoints (listed in the right column of the table.) It is better to take different biological effects into consideration rather than using one endpoint as in present exposure guidelines.**
3. **The studies can be separated into those reporting effects at SAR < 0.4 W/kg (the original guideline limit for whole body RFR exposure) or those reported effects at SAR < 0.08 W/kg (a more recent guideline limit including partial exposure of 'essential' organs). For studies that reported effects at SAR < 0.4 W/kg: Mean= 0.072 W/kg; median = 0.028 W/kg, n=260 (range: 0.000003-0.3957). For studies that reported effects at SAR < 0.08 W/kg: Mean= 0.020 W/kg; median= 0.014 W/kg; n= 174. It is clear that the current RFR exposure guidelines are not valid in the protection of the health detrimental effects of RFR. This new data can be used in setting new guidelines. A perfect approach is to do dose-response studies. But dose-response studies are rare in RFR research.**
4. **This data provides some evidence that 'non-thermal' effects of RFR occur. Since most of the studies were carried out in moving animals, focal heating generating stationary 'hot spots' is unlikely. Even if there was heating, the rise in temperature would be too small to account for the biological effects.**

5. **Another interesting observation is that in my survey, I found 260 studies that reported biological effects at 'low-intensity', and only 17 papers that showed no significant effects (see below). This means that biological systems are very sensitive to RFR, which may have an evolutionary meaning inherited from the process of evolving in the geomagnetic field. Another possible explanation is that when living organisms are exposed to 'high' intensity of RFR, compensatory reactions occur to counteract the perturbation. In prolonged exposure situation, the dose-response curve would assume an invert-U shape. Whereas in the case of 'low-intensity' exposure, compensatory mechanism is not triggered leading to cumulation of effects. Thus, it is possible to see a large ratio of 'effects' vs 'no effect' studies. This also means that low-intensity chronic exposure is more hazardous than higher-intensity exposure.**

Bornhausen M, Scheingraber H. Prenatal exposure to 900 MHz, cell-phone electromagnetic fields had no effect on operant-behavior performances of adult rats. Bioelectromagnetics 21(8):566-574, 2000. (0.0175-0.075 W/kg) (900 MHz. 217 Hz pulse-modulation during pregnancy)

Borzoueisileh S, Shabestani
Monfared A, Ghorbani H, Mortazavi SMJ, Zabihi E, Pouramir M, Doustimotlagh AH, Sh afiee M, Niksirat F. Assessment of function, histopathological changes, and oxidative stress in liver tissue due to ionizing and non-ionizing radiations. Caspian J Intern Med 11(3):315-323, 2020. (0.00557-0.092 W/kg) (radiation from a GSM 900/1800 MHz mobile phone 12 h/day for 14 days)

Dasdag S, Akdag MZ, Ulukaya E, Uzunlar AK, Yegin D. Mobile phone exposure does not induce apoptosis on spermatogenesis in rats. Arch Med Res. 39(1):40-44, 2008. (SAR 0.07-0.57 W/kg) (900 MHz; 2 h/day, 7 days/week for 10 months)

Gurisik E, Warton K, Martin DK, Valenzuela SM. An in vitro study of the effects of exposure to a GSM signal in two human cell lines: monocytic U937 and neuroblastoma SK-N-SH. Cell Biol Int 30(10):793-759, 2006. (0.2 W/kg) (900 MHz, 217-Hz pulses for 2h.

Haidar J, Nabos P, Orlacchio R, Hurtier A, de Gannes FP, Rambert J, Cario-André M, Moisan F, Rezvani HR, Lagroye I, Leveque P, Arnaud-Cormos D, Percherancier Y. Impact of in vitro exposure to 5G-modulated 3.5 GHz fields on oxidative stress and DNA repair in skin cells. Sci Rep. 15(1):31214, 2025. (0.08W/kg) (5G-modulated 3.5 GHz RFR for 24 h.)

Ilgaz NS, Karamazı Y, Emre M, Toyran T, Karaoğlan Ö, Emre T, Dönmez Kutlu M, Öksüz Üçkayabaşı H, Aydın Ç, Yılmaz MB. Genotoxic and histopathological effects of 6 GHz radiofrequency electromagnetic radiation on rat liver tissue. Electromagn Biol Med. 2025 Jul 22:1-12. doi: 10.1080/15368378.2025.2534381. Epub ahead of print. (0.065 W/kg, 6 GHz, 4 h/day for 42 days)

Imai N, Kawabe M, Hikage T, Nojima T, Takahashi S, Shirai T. Effects on rat testis of 1.95-GHz W-CDMA for IMT-2000 cellular phones. Syst Biol Reprod Med. 57(4):204-209, 2011. (0.08 W/kg) (1950 MHz W-CDMA signal; 5 h/day, 7 days/week for 5 weeks)

Krivova NA, Kudabaeva MS, Zaeva OB, Borodina SV, Lepekhina TB, Pavlenko OA, M akhmanazarov RM, Kokin DS, Shipilov SE. The effect of exposure to RF-EMF from the laboratory simulator of 5G NR base station on physiological parameters and cognitive

abilities of male wistar rats of different ages. Sci Rep 14(1):10283, 2024. (0.0322-0.0017 W/kg) (2400 MHz, 4 weeks)
Nazıroğlu M, Özkan FF, Hapil SR, Ghazizadeh V, Çiğ B. Epilepsy but not mobile phone frequency (900 MHz) induces apoptosis and calcium entry in hippocampus of epileptic rat: involvement of TRPV1 channels. J Membr Biol. 248(1):83-91, 2015. (0.23 x 10^{-3} W/kg) (900 MHz, 217 Hz pulses, 1 h)
Okatan DÖ, Okatan AE, Hancı H, Demir S, Yaman SÖ, Çolakoğlu S, Odacı E. Effects of 900-MHz electromagnetic fields exposure throughout middle/late adolescence on the kidney morphology and biochemistry of the female rat. Toxicol Ind Health 34(10):693-702, 2018. (0.012 W/kg) (900 MHz, 1 h/day from postnatal days 35-59)
Porcher A, Wilmot N, Bonnet P, Procaccio V, Vian A. Changes in gene expression after exposing Arabidopsis thaliana plants to nanosecond high amplitude electromagnetic field pulses. Bioelectromagnetics 45(1):4-15, 2024. (10^{-13} to 10^{-16} W/kg) (30,000 EMP over 10 min (180 KHz), pulse duration 500 ps)
Puginier E, Leclercq L, Poulletier de Gannes F, Hurtier A, Orlacchio R, Nabos P, Tijou H, Lévêque P, Arnaud-Cormos D, Percherancier Y, Lagroye I. Biological effects of 5G-modulated 700 MHz RF-EMF exposure on neuronal and glial cell models under isothermal conditions. Sci Rep. 2026 Mar 28. doi: 10.1038/s41598-026-43960-4. Epub ahead of print. (0.08-4 W/kg; 5-G modulated 700 MHz RFR; 1 or 24 h exposure)
Shirai T, Wang J, Kawabe M, Wake K, Watanabe SI, Takahashi S, Fujiwara O. No adverse effects detected for simultaneous whole-body exposure to multiple-frequency radiofrequency electromagnetic fields for rats in the intrauterine and pre- and post-weaning periods. J Radiat Res. 58(1):48-58, 2017. (SAR 0.384-0.433 W/kg) (eight different communication signal EMFs (two of 800 MHz band, two of 2 GHz band, one of 2.4 GHz band, two of 2.5 GHz band and one of 5.2 GHz band; 20 h per day from gestational Day 7 to weaning, and F_1 offspring rats (46-48 F1 pups per group) were then exposed up to 6 weeks of age also for 20 h per day.)
Silva V, Hilly O, Strenov Y, Tzabari C, Hauptman Y, Feinmesser R. Effect of cell phone-like electromagnetic radiation on primary human thyroid cells. Int J Radiat Biol. 92(2):107-115, 2016. (900 MHz for 3 or 16 h at 0.082 W/kg; 895 MHz for 65 h at 0.17 W/kg)
Takahashi S, Imai N, Nabae K, Wake K, Kawai H, Wang J, Watanabe S, Kawabe M, Fujiwara O, Ogawa K, Tamano S, Shirai T. Lack of adverse effects of whole-body exposure to a mobile telecommunication electromagnetic field on the rat fetus. Radiat Res. 173(3):362-372, 2010.((SAR for the dams was 0.066-0.093 W/kg. The SAR for the fetuses and the F(1) progeny was 0.068-0.146 W/kg) (2140 MHz signals were applied for 20 h per day during the gestation and lactation periods.)
Tumkaya L, Kalkan Y, Bas O, Yilmaz A. Mobile phone radiation during pubertal development has no effect on testicular histology in rats. Toxicol Ind Health. 32(2):328-336, 2016. (SAR 0.48 W/kg) (radiation from a mobile phone 895-915 MHz, 217 Hz modulation, 1 h/day for 45 days).
Zeni, O., Di Pietro, R., d'Ambrosio, G., Massa, R., Capri, M., Naarala, J., Juutilainen, J. and Scarfi, M. R. Formation of reactive oxygen species in L929 cells after exposure to 900 MHz RF radiation with and without co-exposure to 3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone. Radiat. Res. 167: 306-311, 2007. (0.3 W/*kg*) (GSM signal or 10 or 30 min)

Biological Effects in Animals and Plants Exposed to Low-Intensity RFR (SAR< 0.4 W/kg)

		SAR (W/kg)	**Effects reported**
Adey et al. (1982)	Cerebral cortex of cats immobilized under local anesthesia; exposed to 450 MHz RFR modulated at 16 Hz for 1 h	0.29	Increased calcium efflux
Aitken et al. (2005)	Mice exposed to 900 MHz RFR, 12 h/day; 7 days	0.09	Genotoxic effect in sperm
Akdag et al. (2016)	Rats exposed to 2400 MHz RFR from a Wi-Fi signal generator for a year	0.000141 (minimum)-0.007127 (maximum)	DNA damage in testes
Alchalabi et al. (2016)	Offspring from pregnant ats exposed to 1800 MHz GSM signal; 1 or 2 h/day for 1, 2, or 3 weeks	0.048	Detrimental effects on pre- and postnatal development
Alkis et al. (2019a)	Rats exposed to 900; 1800; and 2100 MHz RFR; 2 h/day; 6 months	Brain SAR: 900 MHz - 0.0845; 1800 MHz-0.04563; 210 MHz-0.03957	DNA single strand break and oxidative damages in frontal lobe
Alkis et al. (2019b)	Rats exposed to 900; 1800; and 2100 MHz RFR; 2 h/day;6 months	Brain SAR: 900 MHz - 0.000333; 1800 MHz-0.002647; 210 MHz-0.002815	DNA strand beaks and oxidative DNA damage in testicular tissue

Amiri et al. (2023)	Liver of rats exposed to 2450 MHz RFR from a Wi-Fi router; 4 h/day for 4 weeks	0.03	Decreased superoxide dismutase and catalase CA, increased lipid peroxidation, attenuated by swimming
Arendash et al. (2010)	Normal and transgenic Mice exposed to 918 MHz RFR, 2 h/day for 2-8 months	0.25	Improved cognitive behavior, decreased amyloid-β deposition in brain
Atasoy et al. (2013)	Rats exposed to 2437 MHz (Wi-Fi) RFR; 24 h/day for 20 weeks	maximum 0.091	Oxidative DNA damage in blood and testes
Arslan et al. (2024)	Rats exposed to 217-Hz modulated 1800 MHz RFR; 2 h/day for 8 weeks	0.06	p38MAPK gene expression up-regulated in brain
Aynali et al. (2013)	Laryngotracheal mucosa of rats exposed to 2450 MHz RFR; 1 h/day for 28 days	0.143	Increased lipid peroxidation; decreased glutathione peroxidase; attenuated by melatonin
Bakacak et al. (2015)	Female rats exposed to 900 MHz RFR 15 min/day for 15 days at the abdominal region	0.018 - 4	Decrease in the number of ovarian follicles
Barteri et al. (2016)	Lactoperoxidase and horseradish peroxidase exposed to 900 MHz RFR modulated at 217 Hz, 30 min,	0.00004	RFR caused conformational changes of the active sites of the enzymes and influenced the formation and stability of the intermediate free radicals.
Bedir et al. (2018)	Rat exposed to 2100 MHz RFR, 6 or 19 h/day, 30 days	0.024	Oxidative process-mediated renal injury

Bektas et al. (2022)	Brain of normal and diabetic rats exposed to 3,500 MHz RFR, GSM-modulated; 2 h/day for 30 days	0.323	Increased total oxidant status and H_2O_2, decreased total antioxidant status.
Bektas et al. (2023)	Muscle of normal and diabetic rats exposed to 900 MHz, 1800 MHz, 2100 MHz RFR; 2 h/day for 1 month	0.026, 0,164, 0.173	Increased lipid peroxidation and ischemia-modified albumin; decreased catalase, and glutathione
Bektas et al. (2024)	Cardiac blood and fat tissue from normal and diabetic rats exposed to 3500 MHz RFR 2 h/day, 5 days/week for 1 month	0.037	Total oxidant status, total antioxidant status, and H_2O_2 level affected by RFR and diabetic condition (mostly increases); tissue-dependent effects observed.
Bektas et al. (2026a)	Mouse dorsal root ganglion neurons exposed to 3.5 GHz RFR (217 Hz modulation, 12.5% duty cycle) for 1-24 h	0.171	Increased ROS and apoptosis.
Bektas et al. (2026b)	Testis of rats exposed to GSM-modulated 3.5 GHz RFR; 2 h/day for 30 days.	0.02669	Decreased TAS, increased TOS and MDA, decreased testosterone, LH and FSH
Belyaev et al. (2005)	Human white blood cells exposed to 915 MHz GSM signal, 24 or 48 h	0.037	Genetic changes
Belyaev et al. (2009)	Human white blood cells exposed to 915 MHz, 1947 MHz; GSM, UMTS signals; 24 or 72 h	0.037	Affected DNA repair mechanism

Bilgici et al. (2018)	Rats exposed to 2450 MHz RFR 1 h/day for 30 days	0.0233	Increased inflammation and testicular damage
Blackman et al. (1980)	Forebrain of chicken exposed to 50 MHz, AM at 16 Hz, 20 min	0.0014	Affected calcium efflux
Blackman et al. (1989)	Forebrain of chicken exposed to 50 MHz, AM at 16 Hz, 20 min	0.00036	Affected calcium efflux
Bodera et al. (2015)	Blood, liver, kidney, and brain of healthy rats and rats with persistent inflammatory state exposed to 1800 MHz RFR, 15 min/day for 5 days	0.028	Increased lipid peroxidation in brain, blood, and kidney after RFR + tramadol.
Bodin et al. (2023)	Pregnant rats and offspring exposed to 3500 MHz continuous wave RFR for 22 h/day from gestational day 8 to post-natal day 21	0.07	Disturbance in open field behavior and delayed incisor eruption
Bodin et al. (2025)	Mouse neuroepithelial stem cells exposed to GSM-900 MHz RFR for 3 or 7 days	0.08	Increased double strand DNA breaks and apoptosis
Bourdineaud et al. (2017)	Earthworm (Eisenia fetida) exposed to 900 MHz RFR, 2 h	0.00013-0.009	DNA modification. increased catalase gene expression
Bozok et al. (2023)	Pregnant rats exposed to 900, 1800, or 2100 MHz RFR for 6, 12, or 24 h/day for 20 days	0.087-0.17	Myocardial tissue damage observed, increased lipid peroxidation, decreased antioxidation (dependent on frequency and exposure duration)

Burlaka et al. (2013)	Embryos of Japanese quails exposed to GSM 900 MHz RFR; 38 h, 5 or 10 days	0.000003	Increased $O_2^{\cdot -}$, nitric oxide, 8-hydroxydeoxyguanosine; decreased superoxide dismutase and catalase
Cakir et al. (2025)	Serum and testis of rats exposed to 2450 MHz RFR 2 h/day for 30 days	0.00588	Increased lipid peroxidation; decreased SOD, GSH, and GPx.
Çakmak et al. (2026)	Testis of rats exposed to 2450 MHz RFR. 1 h/day for 60 days	0.00208	Increased VEGFA gene expression and caused morphological effects in testis.
Calis et al. (2021)	Pregnant rats exposed to 1800 MHz RFR, 1 h/day during whole pregnancy	0.23	Female offspring have lower mean number of primordial and secondary follicles, and a higher atresia score
Cantu et al. (2023)	Human keratinocytes exposed to 900 MHz RFR for 1 h	0.00155	Six common DNA targets that were both differentially methylated and differentially expressed
Cao et al (2015)	Plasma from rats exposed to 1800 MHz RFR, 2 h/day for 32 days	0.05653	Circadian rhythms of melatonin, glutathione peroxidase and superoxide dismutase shifted.
Cappucci et al. (2022)	Head, ovary, and testis of Drosophila melanogaster exposed to 2437 MHz RFR (Wi-Fi) from embryo to adult stage	0.0608	Increased gene expression of hsp70, induced gene instability, and increased DNA damage, Increased reactive oxygen species
Capri et al. (2004)	Human lymphocytes exposed to 900 MHz, GSM signal, 1 h/day, 3 days	0.07	Cell proliferation and membrane chemistry

Čermak et al. (2020)	V79 cells exposed to 915-MHz GSM-modulated RFR for 1, 2, or 3 h.	0.23, 0.8, or 1.6	Microtubular structure impairment at 0.23 W/kg for 3 h
Cetin et al. (2014)	Pregnant rats and offspring exposed to 900 or 1800 MHz RFR, 1 h/day during pregnancy and postnatal period (to 6th week)	0.15	Brain and liver glutathione peroxidase activities, as well as liver vitamin A and β-carotene concentrations decreased in the offspring, whereas brain iron, vitamin A, and β-carotene concentrations increased in the exposed groups.
Ceyhan et al. (2012)	Skin of rats exposed to pulsed 2450 MHz RFR; 1 h/day for 4 weeks	0.064	Decreased superoxide dismutase and glutathione peroxidase, increased catalase and lipid peroxidation.
Chandel et al. (2019a)	Onion roots (Allium cepa L.) exposed to 2350 MHz RFR for 1, 2, or 4 h	0.313	Increased mitotic index and chromosomal aberration; significant increase in DNA single strand breaks at 2 and 4 h.
Chandel et al. (2019b)	Onion roots (Allium cepa L.) exposed to 2100 MHz RFR for 1 or 4 h	0.282	Increased mitotic index, chromosomal aberration, and DNA single strand breaks after 4 h of exposure.
Chaturvedi et al. (2011)	Brain cells of rats exposed to 2450 MHz RFR, 2 h/day for 30 days	0.03561	Increased DNA strand breaks
Chauhan et al. (2017)	Liver, brain, spleen, kidney, and testis of rats exposed to 2450 MHz RFR, 2 h/day for 35 days	0.14	Increased lipid peroxidation in liver, brain, and spleen.
Chen et al. (2014)	Male mice exposed to 1800 MHz RFR 2 h/day for 32 days	0.2221	Reduced testicular sperm head count and serum testosterone, increased

			serum estradiol. circadian rhythms of testicular sperm head count and estradiol disappeared after exposure.
Comelekoglu et al. (2018)	Sciatic nerve of rats exposed to 1800 MHz RFR, 1 h/day, 4 weeks	0.00421	Changes in electrical activity, increased catalase, and degeneration of myelinated fibers
Coskun et al. (2024)	Parotid gland of rats exposed to 1800 MHz RFR, 6 or 12 h/day for 30 days	0.117	Increased total oxidant level, decreased total antioxidant status, increased apoptosis and histopathology
D'Andrea et al. (1986)	Rats exposed to 2450 MHz RFR 7 h/day.7 days/week for 90 days	0.14 (0.11-0.18)	Affected shuttle box performance and schedule-controlled behavior.
Dasdag et al. (2015)	Rats exposed to 2450 MHz RFR 24 h/day for 1 year	0.00242	Increased Sperm head defect; decreased weight of the epididymis and seminal vesicles, seminiferous tubules diameter and tunica albuginea thickness
Delavarifar et al. (2020)	Male mice exposed to 2450 MHz RFR; 2 h/day for 4 days	0.03- 0.092	Increased sperm concentration
Demirbağ et al. (2023)	Rats exposed to 1800 MHz RFR 1 h/day for 30 days	Maximum in body 0.0029; at testis: 0.001	Ultrastructural changes seminiferous tubule and Leydig cells in the testis of RFR group; Increased lipid peroxidation, decreased catalase and superoxide dismutase
De Pomerai et al. (2003)	Protein exposed to 1-GHz RFR, 24 or 48 h	0.015	Protein damages

Deshmukh et al. (2013a)	Rats exposed to 900, 1800, and 2450 MHz RFR; 2 h/day for 30 days	0.0006-0.0007	DNA strand breaks in brain
Deshmukh et al. (2013b)	Rats exposed to 900 MHz; 2 h/day for 30 days	8.47×10^{-5}	Increased lipid peroxidation and protein oxidation in blood
Deshmukh et al. (2015)	Rats exposed to 900, 1800, and 2450 MHz RFR; 2 h/day for180 days	0.0006-0.0007	Declined cognitive functions, increased brain HSP70 and DNA strand break
Deshmukh et al. (2016)	Rats exposed 900, 1800, and 2450 MHz; 2 h/day for 90 days	0.0006-0.0007	Declined cognitive functions, increased brain HSP70 and DNA strand break in rats
D'Inzeo et al. (1988)	Cultured chick microtubes exposed to 10.75 GHz; 30-120 sec	0.008	Operation of acetylcholine-related ion-channels in cells
Djordjevic et al. (2015)	Liver of rats exposed to 900 MHz RFR from a mobile phone; 4 h/day for 20. 40, or 60 days	0.089	Depending on exposure duration, increased lipid peroxidation, protein oxidation, catalase, and 8-hydroxydeoxyguanosine
Durdik et al. (2019)	Human umbilical cord blood cells including CD34+ hematopoietic stem/progenitor cells exposed to GSM 900 RFR; 1 h	0.004 -0.040	Increased reactive oxygen species
Dutta et al. (1984)	Human neuroblastoma cells exposed to 915 MHz RFR, sinusoidal AM at 16 Hz, 30 min	0.05	Increase in calcium efflux

Dutta et al. (1989)	Human neuroblastoma cells, 147 MHz, AM at 16 Hz, 30 min	0.005	Increase in calcium efflux
Dutta et al. (1994)	Escherichia coli cultures containing a plasmid with a mammalian gene for enolase were exposed for 30 min to 147 MHz RFR AM at16 or 60 Hz	0.05	Enolase activity in exposed cultures RFR at AM at 16 Hz showed enhanced activity Enhanced, and AM at 60 Hz showed reduced activity (Modulation frequencies. 16 and 60 Hz, caused similar effects.)
Eberhardt et al. (2008)	Rats exposed to 900 MHz GSM RFR for 2 h	0.00012-0.12	Changed blood-brain barrier permeability and nerve cell damage in the brain
Echchgadda et al. (2022)	Rat primary hippocampal neurons exposed to 3000 MHz RFR for 1 h	Average 0.3	Decreased amplitude of action potential (AP) and resting membrane potential (MP), and increased neuronal excitability and synaptic transmission
Eker et al. (2018)	Rats exposed to 1800 MHz RFR, 2 h/day for 8 weeks	0.06	Increased caspase-3 and p38MAPK expressions in eye.
Elekes et al. (1996)	Mice exposed to 2450 MHz (continuous-wave or amplitude modulated at 50 Hz square wave) RFR, 3h/day for 6 days	0.14	Increased antibody producing cells in spleen of male mice. (No effect on female mice.)
Emre et al. (2026)	Blood of rats exposed to 6 GHz RFR; 4 h/day for 6 weeks	0.083	Decreased GSH, CAT, SOD, and LPO.

Er et al. (2022)	Testis of rats exposed to 900 MHz RFR, 2 h/day, 5 day/week for 1 or 10 weeks	whole body 1.157, testis 0.107	Increase in the RFR group in the acute period, whereas no difference in the chronic groups for the apoptotic indices (capase-3 and Bcl-xl); p-p38 and p-JNK protein expressions increased significantly in RFR groups in both periods.
Er et al. (2025)	Brain of rats exposed to 2100 MHz RFR, 2 h/day, 5 day/week for 1 or 10 weeks	0.27	Increased lipid peroxidation and protein carboxylation, decreased SOD and CAT only in 1-week exposure group.
Er et al. (2026)	Brain from rats exposed to 2100 MHz RFR for 2h/day for 7 days or 10 weeks	0.128 (whole body); 0.22 (brain)	Chemical, auditory electrophysiological, and morphological changes observed. 7-day and 10-week exposure produced opposite electrophysiological effects.
Ertilav et al. (2018)	Hippocampal and dorsal root ganglion neurons of rats exposed to 900 or 1800 MHz RFR modulated at 217 Hz; 1 h/day (5 days/week) for 1 year	0.15	Increased reactive oxygen species (calcium involved)
Esmekaya et al. (2011)	Human peripheral blood lymphocytes exposed to 1800 MHz GSM- (217 HZ) modulated RFR for 6, 8, 24, or 48 h	0.21	Chromatin changes and increases in sister chromatin exchange.
Falcioni et al. (2018)	Rats exposed to 1800 MHz RFR from prenatal life to death at 19 h/day	0.1, 0.03, or 0.001	Increase in tumors in brain and heart

Forgacs et al. (2006)	Mice exposed to 1800 MHz RFR, GSM- 217 Hz pulses, 576 µs pulse width; 2 h/day, 10 days	0.018	Increase in serum testosterone
Furtado-Filho et al. (2014)	Pregnant rats exposed to 950 MHz RFR for 0.5 h/day for 51 days (21 days of gestation and 6-30 days old)	SAR of pregnant rat 0.01-0.03 W/kg; neonate 0.88 W/kg, 6-day old 0.51 W/kg, 15-day old 0.18 W/kg, 30-day old 0.06 W/kg	Decreased DNA strand breaks in liver of 15-day old and increased breaks in 30-day old offspring.
Garaj-Vrhovac et al. (2011)	Operators of two types of marine radars (3, 9.4, and 5.5 GHz); average time on job 2-16 years	0.0005-0.004 (time averaged)	Increased genetic damage in blood lymphocytes
Gautam et al. (2024)	Rats exposed to 2350 MHz RFR for 2 h/day for 56 days	0.0625	Male reproductive system, hematological system, liver, and kidney affected; reduction in testosterone, total antioxidant capacity, and increased lipid peroxidation in testis.
Gautam et al. (2025)	Rats exposed to 35.5 MHz RFR; 2 h/day for 60 days	0.07-0.0564	Sperm damage; increased DNA strand breaks; increased lipid peroxidation, decreased superoxide dismutase and total antioxidant status.

Gelenli Dolanbay et al. (2025)	Testis of offspring of rats exposed to 3.5 GH GSM RFR 2h/day throughout pregnancy or the last two weeks of pregnancy;	Peak SAR 0.03825 (over 1 g tissue); 0.006622 (over 10 g tissue)	Morphological changes in testis, Incraesed γ-H2AX (double strand DNA breaks) and autophage and apotosis. No difference in responses between the two schemes of exposure.
Ghazizadeh and Nazıroğlu (2014)	Hippocampal cells of pentylentetrazol-induced epileptic rats exposed to 2450 MHz (Wi-Fi) RFR; 1 h	0.000052	enhanced reactive oxygen species in epileptic rat hippocampus
Gökçek-Saraç et al. (2017)	Rats exposed to 900 MHz or 2100 MHz RFR, 2 h/day for 1 week or 10 weeks	900 MHz (whole body SAR 0.0053 W/kg); 2100 MHz (0.128 W/kg)	Enzymes of N-methyl-D-aspartate receptor-related signaling pathways in hippocampus higher in 10-week than in 1-week group
Gremiaux et al. (2016)	Rose exposed to 900 MHz RFR, 3x 39 min every 48 h at 2 stages of development	0.00072	Delayed and reduced growth
Grigor'ev et al. (2010)	Blood serum of rats exposed to 2450 MHz RFR; 7 h/day for 30 days	0.16	Increased nitric oxide reaction products, lipid peroxidation, and hydroxylated fatty acids
Gulati et al. (2020)	Human lymphocytes exposed to UMTS signals at different frequency channels used by 3 G mobile phone (1923, 1947.47, and 1977 MHz) for 1 or 3 h	0.04	DNA damage found only in cells exposed to 1977-MHz field
Güler et al. (2016)	Rabbit exposed to 1800 MHz 217-Hz modulated RFR in	0.018	Increased 8-OHdG and lipid peroxidation in brain tissue

	utero and extra-utero		
Gupta et al. (2018)	Rats exposed to 2450 MHz RFR; 1 h/day for 28 days	0.0616	Cognitive deficit, loss of mitochondrial functions, activation of apoptotic factors in hippocampus; affected cholinergic system
Gürler et al. (2014)	Brain and blood from rats exposed to 2450 MHz RFR; 1 h/day for 30 days	0.02	Increased lipid peroxidation in male and female; increased 8-hydroxydeoxyguanosine in female animals
Halgamuge et al. (2015)	Growth parameters of soybean seedlings; 2 h	GSM 217-Hz modulated (4.8×10^{-7}, 4.9×10^{-5}, and 0.0026 W/kg) or CW (0.00039 and 0.02 W/kg) 900-MHz	Modulated and CW fields produced different patterns of growth effects. There was an amplitude effect and extremely low-level modulated field (4.8×10^{-7} W/kg) affected all parameters
Hancı et al. (2013)	Rats exposed to 900 MHz RFR for 1 h/day during 13-21 days of pregnancy; testis of offspring examined on postnatal day 21	0.0265	RFR caused irregularities in seminiferous tubule basal membrane and epithelium, immature germ cells in the lumen, and a decreased diameter in seminiferous tubules and thickness of epithelium; increased apoptotic index, lipid peroxidation and DNA oxidation
Hancı et al. (2015)	Rats exposed to 900 MHz RFR for 1 h/day during 13-21 days of pregnancy;	0.025	Pathological changes in cell morphology in the thymic and splenic tissues;

	spleen and thymus of offspring examined on postnatal day 21		lipid peroxidation increased and glutathione decreased in thymus whereas both were increased in the spleen.
Hanci et al. (2018)	Rats exposed to 900 MHz RFR, 1 h/day to postnatal day 60.	0.0067	Changes in morphology and increase in oxidative stress marker in testis
Hanci et al. (2025)	Offspring of pregnant rats exposed (1 h/day on day1-21 of pregnancy) to 900 MHz RFR	0.0173, 0.0063, 0.0059 depending on size of animal	Change in morphology and oxidative damage in sciatic nerve.
Hatice et al. (2014)	Blood and brain of rats exposed to 2450 MHz RFR; 1 h/day for 30 days	0.02	Increased 8-hydroxydeoxyguanosine in plasma and brain and protein oxidation only in blood plasma
He et al. (2016)	Mouse bone marrow stromal cells exposed to 900 MHz RFR 3 h/day for 5 days	2.5×10^{-4}	Increased expression of PARP-1 mRNA
He et al. (2017)	Mouse bone marrow stromal cells exposed to 900 MHz RFR 3 h/day for 5 days	2.5×10^{-4}	Increased mRNA of poly(ADP-ribose) polymerase-1, cells treated with RFR and gamma radiation showed less genetic damage and faster kinetics of repair.
Hidisoglu et al. (2018)	Temporal cortex of rats exposed to GSM 2100 MHz RFR, 2 h/day for 7 days	Brain 0.27	Increased lipid peroxidation

Hekmat et al. (2013)	Calf thymus exposed to 940 MHz RFR, 45 min	0.04	Conformational changes in DNA
Ivaschuk et al. (1997)	Nerve growth factor-treated PC12 rat pheochromocytoma cells 836.55 MHz TDMA signal, 20 min	0.026	Transcript levels for c-jun altered
Jech et al. (2001)	Narcoleptic patients; 900 MHz, GSM- 217 Hz pulses, 577 μs pulse width; 45 min	0.06	Improved cognitive functions
Jha et al. (2025)	Overy of rats exposed to 700 MHz RFR; 6 h/day for 10 days or 4 h/day for 60 days	0.375	Increased Oxidative lipid damage and decreased SOD; morphological changes
Jonwal et al. (2018)	Mice exposed to 2450 MHz RFR; 2 h/day for 30 days	0.09	In testis: increased catalase, lipid peroxidation, reactive oxygen species, decreased glutathione peroxidase, testosterone, and superoxide dismutase; histopathological changes in seminiferous tubules; increased micronucleus in blood.
Jooyan et al. (2019)	Chinese hamster ovary cells exposed to 900 MHz RFR for 24 h	0.3	Decreased clonogenic ability, increased DNA strand break, increased ROS
Jooyan et al. (2023)	Chinese hamster ovary cells exposed to 900 MHz RFR (217-Hz modulation) for 24 h	0.2-0.4	Increased single strand DNA breaks, no effect on micronuclear formation, No effect on COX-2 gene expression.

Karadayi et al. (2024)	Rats exposed to 2450 MHz RFR 1 h/day during pregnancy and offspring to 45 days old	0.00051	Increased in soluble Receptor Activator of Nuclear factor-kB Ligand (sRANKL) and Osteoprotegerin (OPG) in serum and tibia; increased apoptosis. (sRANKL-involved in bone regeneration and remodeling; OPG-protein in regulation of bone density.)
Karamazi et al. (2025)	Pregnant rats exposed to 6,000 MHz RFR, 4 h/day in first 18 days of gestation	0.054	Fetal bone development affected.
Katirci et al. (2024)	Rats exposed to 2100 MHz RFR; 2 h/day for 1 or 10 weeks	Whole body 0.16; testis 0.0347	Affected Tyro 3, Axl, and Mer (TAM) receptors and their ligands in testes, essential for spermatogenesis and testosterone production.
Keleş et al. (2019)	Rats exposed to 900 MHz RFR; 1 h/day for 25 days	0.012	Higher number of pyramidal and granule neurons in hippocampus
Keleş et al. (2024)	Rats exposed to 900 MHz RFR; 1 h/day for 25 days	0.01 (from Aslan et al. Biotechnic &Histochemistry 92:324-330, 2017)	Increased lipid peroxidation, glutathione, catalase, and superoxide dismutase in kidney
Kerimoğlu et al. (2016a)	Lumbar spinal cord of rats exposed to 900 MHz RFR; 1 h/day on postnatal days 22-60	0.0093	Increased lipid peroxidation; decreased superoxide dismutase, glutathione
Kerimoğlu et al. (2016b)	Brain of rats exposed to 900 MHz RFR; 1 h/day	0.0093	Increased lipid peroxidation, glutathione; decreased catalase

	on postnatal days 21-60		
Kerimoğlu et al. (2016c)	Heart of rats exposed to 900 MHz RFR; 1 h/day on postnatal days 21-59	0.0093	Increased lipid peroxidation, superoxide dismutase; decreased glutathione, catalase
Kerimoğlu et al. (2018)	Sciatic nerve of rats exposed to 900 MHz RFR; 1 h/day on postnatal days 21-59	0.0093	Increased lipid peroxidation, superoxide dismutase, catalase
Kesari and Behari (2009)	Rats exposed to 50 GHz RFR; 2 h/day for 45 days	0.0008	Double strand DNA breaks observed in brain cells
Kesari and Behari (2010a)	Rats exposed to 50 GHz RFR; 2 h/day for 45 days	0.0008	Changes in oxidative processes and apoptosis in reproductive system
Kesari and Behari (2010b)	Sperm of rat exposed to 2450 MHz RFR; 2 h/day for 35 days	0.11	Decreased glutathione peroxidase, superoxide dismutase; increased catalase
Kesari et al. (2010)	Rats exposed to 2450 MHz RFR at 50-Hz modulation, 2 h/day for 35 days	0.11	DNA double strand breaks in brain cells
Kesari et al. (2014)	Rats exposed to a 3D cell phone. 2 h/day for 60 days	0.26	Increased DNA double strand breaks, micronuclei, Caspase 3 and apoptosis in brain cells; activation of hsp27/p38MAPK stress pathway.
Kues et al. (1992)	Monkeys (M. mulatta and M. fascicularis) treated with timolol or pilocarpine exposed	0.26	Corneal endothelial damage

	to pulsed 2450 MHz RFR, 4 h/day for 3 days		
Kulaber et al. (2017)	Thymus of rats exposed to 900 MHz RFR; 1 h/day between postnatal days 22-59	0.067	Increased lipid peroxidation
Kumar et al. (2010a)	Rats exposed to 10 GHz RFR, 2 h/day for 45 days	0.014	Cellular changes and increase in reactive oxygen species in testes
Kumar et al. (2010b)	Rats exposed to 10 GHz RFR, 2 h/day for 45 days; or 50 GHz, 2 h/day for 45 days	0.014 (10 GHz); 0.0008 (50 GHz)	Genetic damage in blood cells
Kumar et al. (2011a)	Rats exposed to 2450 MHz RFR; 2 h/day for 60 days	0.014	Increases in caspase and creatine kinase in sperm and decreases in testosterone and melatonin in blood
Kumer et al. (2011b)	Spermatozoa of rats exposed to 10 GHz RFR, 2 h/day for 45 days	0.014	Increased reactive oxygen species
Kumar et al. (2012)	Rats exposed to 10-GHz RFR; 2 h/day for 45 days	0.014	Increased creatine phosphate and decreased melatonin and lipid peroxidation in sperms
Kumar et al. (2013)	Rats exposed to 10-GHz RFR; 2 h/ day for 45 days	0.014	Increased micronucleus in blood cells and DNA strand breaks in spermatozoa.
Kumar et al. (2016)	Zea mays seedling exposed to 1800-MHz RFR, for 0.5, 1, 2, or 4 h	0.169	longer exposure of 4 h caused significant growth and biochemical alterations

Kumar et al. (2020)	Onion exposed to 900 MHz or 1800 MHz RFR for 0.5-4 h	900 MHz- 0.092; 1800 MHz- 0.169	Effects on root length and thickness, micronucleus formation. DNA strand breaks observed. 1800 MHz more potent that 900 MHz field
Kumar et al. (2021)	Hippocampus of rats exposed to 900, 1800, or 2450 MHz RFR for 2 h/day for 1-month, 3-month and 6-month	Rats exposed to 900 MHz, 1800 MHz, and 2450 MHz RFR at a SAR of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg, respectively.	Significant epigenetic modulations were observed in the hippocampus, larger changes with increasing frequency and exposure duration.
Kunjilwar and Behari (1993)	Rats exposed to 147 MHz and subharmonic 73.5 and 36.75 MHz amplitude modulated at 16 and 76 Hz; 2 h/day for 30-35 days	0.1-0.14	Decreased acetylcholine esterase in brain
Kuybulu et al. (2016)	Rats exposed to 2450 MHz RFR either prenatally (in utero) or postnatally (18 days to 12^{th} week old); 1h/day	0.143	Caused chronic kidney damages- histologically and biochemically. Increased lipid peroxidation; decreased superoxide dismutase
Kuzay et al. (2017)	Testis of normal and diabetic rats exposed to 2100 MHz RFR; 20 min/day, 5 day/week for one month.	0.23	Increased lipid peroxidation and nitric oxide; decreased glutathione

Kwee et al. (2001)	Transformed human epithelial amnion cells exposed to 960 MHz GSM signal, 20 min	0.0021	Increased Hsp-70 stress protein
Lameth et al. (2025)	Cerebral cortex of Rats head exposed to 3.5 GHz RFR, 1 h/day (5 days/week) for 6 weeks.	0.19	Up-regulation of genes related to glutamatergic synapses
Lerchl et al. (2008)	Hamsters exposed to 383 MHz (TETRA), 900 and 1800 MHz (GSM) 24 h/day, 60 days	0.08	Metabolic changes in hamster
Lian et al. (2018)	Yeast strains (NT64C and SB34) exposed to 2000 MHz RFR for 96 h	0.12	Increased generation and propagation of yeast prions, level of reactive oxygen species, and activities of superoxide dismutase and catalase
Lin et al. (2016)	Budding yeast exposed to 2000 MHz RFR for 96 h	0.12	Upregulate the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not the glycolysis pathway.
López-Furelos et al. (2016)	Rats exposed to 900 or 2450 MHz RFR or combination of the two frequencies for 1-2 h	0.0367-0.0723 (average whole body)	Changes in HSP 90 and 70 levels in cerebrum and cerebellum
López-Furelos et al. (2018)	RAW 264.7 cells (mouse macrophage-like leukemia virus transformed cells) exposed to 900 and 2450 MHz single or combined RFR; 4, 24, 48, or 72 h	0.0842-0.406	Increased nitric oxide depending on exposure time. (Decreased phagocytic activity)

López-Martín et al. (2009)	Picotoxin-induced seizure-prone rats exposed to pulse-modulated GSM and unmodulated signals; 2 h	0.03-0.26	c-Fos expression in brain
Maalouf et al. (2023)	Adipose tissues of rats exposed to 900 MHz CW RFR; 1 h twice a day for 3 or 7 days	0.1 or 0.4	Changed (increase and decrease) expression of genes involved in lipid, metabolism, energy homeostasis, and thermal regulation,
Manta et al. (2014)	Drosophila melanogaster exposed to radiation from a wireless DECT (Digital Enhanced Cordless Telephone) base radiation (1.88-1.90 GHz; pulsed (at 100 Hz rate and 0.08 ms duration) for 0.5 - 96 h	0.009	Increased reactive oxygen species in male and female at 6 h; ovary reactive oxygen species level increased after 0.5 h and reached maximum after I h exposure
Manta et al. (2017)	Ovary of Drosophila melanogaster exposed to radiation from a GSM 1800 MHz mobile phone in talk mode for 30 min	0.15	Increased reactive oxygen species production immediately, non-targeted transcriptional reprogramming of gene expression at 2 h, and apoptosis at 4 h post-exposure.
Makova et al. (2005)	Human white blood cells exposed to 915 and 905 MHz GSM signal, 1 h	0.037	Altered chromatin conformation
Markova et al. (2010)	Human diploid VH-10 fibroblasts and human adipose-tissue derived mesenchymal stem cells exposed to GSM (905 MHz or 915 MHz) or	0.037-0.039	Inhibited tumor suppressor TP53 binding protein 1 (53BP1) foci that are typically formed at the sites of DNA double strand break location.

	UMTS (1947.4 MHz, middle channel) RFR for 1, 2, or 3 h		
Marinelli et al. (2004)	Human leukemia cell exposed to 900 MHz CW RFR 2 - 48 h	0.0035	Cell's self-defense responses triggered by DNA damage.
Meena et al. (2014)	Rats exposed to 2450 MHz RFR; 2 h/day for 45 days	0.14	Induced oxidative stress in testis; effects reversed by melatonin
Megha et al. (2012)	Rats exposed to 900 MHz or 1800 MHz, 2 h/day for 30 days	900 MHz - 0.00059; 1800 MHz - 0.00058	Impaired cognitive functions; Increased lipid peroxidation, and protein oxidation; decreased glutathione in brain
Megha et al. (2015a)	Rats exposed to 900 and 1800 MHz RFR for 30 days (2 h/day, 5 days/week)	0.00059 and 0.00058	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.
Megha et al. (2015b)	Rats exposed to 900, 1800, and 2450 MHz RFR for 60 days (2 h/day, 5 days/week)	0.00059, 0.00058, and 0.00066	Increased DNA damage in the hippocampus
Migdal et al. (2023)	Bees exposed to 900 MHz RFR for 0.25, 1, or 3 h	0.05, 0.3, or 1.4	Increased expression of Hsp70 and Hsp 90 genes (at 0.05 W/kg for 3 h)
Misa Agustiño et al. (2012)	Rats exposed to 2450 MHz RFR for 30 min	0.046	Decreased HSP-90 and HSP-70 in thyroid gland.

Mohammed et al. (2013)	Rats exposed to 900 MHz continuous-wave, 900 MHz modulated at 8 and 16 Hz; 1 h/day for 1 month	Spatial peak SAR 0.245	Increased latency of REM sleep
Nakamura et al. (1998)	Pregnant rats exposed to 2450 MHz RFR for 90 min	0.36-0.44	Affected beta-endorphin in blood and anterior pituitary gland, blood progesterone, and splenic natural killer cell activity
Navakatikian and Tomashevskaya (1994)	Rats exposed to 2450 MHz CW and 3000 MHz pulse-modulated 2-μs pulses at 400 Hz, Single (0.5-12 h) or repeated (15-60 days, 7-12 h/day)	0.0027	Behavioral and endocrine changes, and decreases in blood concentrations of testosterone and insulin. CW-no effect
Naziroğlu and Gümral (2009)	Brain of rats exposed to 2450 MHz (217 Hz pulses) RFR; 1 h/day for 28 days	0.1434	Decreased vitamin C, E, and A
Nazıroğlu et al. (2012a)	Human leukemia 60 cells exposed to 2450-MHz RFR for 1, 2, 12, or 24 h	0.11	Increased in cytosolic free Ca^{2+} concentrations; increased lipid peroxidation
Nazıroğlu et al. (2012b)	Brain and dorsal root ganglion neuron of rats exposed to 2450 MHz 217 Hz modulation RFR; 1 h/day for 30 days	0.1	Increased lipid peroxidation in dorsal root ganglion neurons, attenuated by melatonin (RFR induced calcium influx in brain and ganglion neurons attenuated by melatonin.)

Nittby et al. (2008a)	Rats exposed to 915 MHz GSM signal, 6 h	0.013 (whole body average SAR); 0.03 (head)	Altered gene expression in cortex and hippocampus
Nittby et al. (2008b)	Rats exposed to GSM-900 MHz RFR, 2 h/week for 55 weeks	0.0006	Cognitive impairment
Odaci and Özyılmaz (2015)	Testis of rats exposed 900 MHz RFR; 1h/day for 30 days.	0.025	Produced vacuoles in seminiferous tubules basal membrane and edema in the inter-tubular space and apoptosis; decreased lipid peroxidation, catalase, superoxide dismutase, and glutathione.
Odaci et al. (2015)	Pregnant rats exposed to 900 MHz RFR, 1 h/day, on days 13-21 of pregnancy.	0.024	Kidney tissue of 21-day old male offspring showed histological degeneration, increased lipid peroxidation. And decreased catalase and superoxide dismutase.
Odaci et al. (2016)	Pregnant Sprague - Dawley rats exposed to 900 MHz RFR 1 h/day during days 13 - 21 of pregnancy.	0.024	Testis and epididymis of offspring showed higher DNA oxidation
Okatan et al. (2018)	Ovary of rats exposed to 900 MHz RFR; 1 h/day from 35-59 days old	0.0098	Histopathological changes observed
Okatan et al. (2019)	Liver of rats exposed to 900 MHz RFR; 1 h/day on 35-59 postnatal days	0.0096	Decreased 8-hydroxydeoxyguanosine and superoxide dismutasis

Oksay et al. (2014)	Testis of rats exposed to 2450 MHz RFR; 1 h/day for 30 days	0.1	Increased lipid peroxidation; attenuated by melatonin
Özdemir et al. (2021)	Optic nerve of rats exposed to LTE-Advanced Pro (4.5 G) mobile phone (00-2600 MHz); 2 h/day for 6 weeks	0.0035 at eye	Increased lipid peroxidation; decreased catalase and superoxide dismutase
Ozguner et al. (2005a)	Kidney of rats exposed to 900 MHz RFR; 30 min/day for 3 months	0.016	Increased lipid peroxidation and nitric oxide; decreased superoxide dismutase, catalase, and glutathione peroxidase
Ozguner et al. (2005b)	myocardial tissue of rats exposed to 900 MHz (217 Hz pulse modulation) RFR; 30 min/day for 10 days	0.016	Increased lipid peroxidation and nitric oxide; decreased superoxide dismutase, catalase, and glutathione peroxidase
Ozgur et al. (2010)	Guinea pigs exposed to 1800-MHz GSM signal, 10 or 20 min/day for 7 days	0.38	Changes in oxidative status in the liver
Ozlem Nisbet et al. (2012)	Rats exposed to 1800 or 900 MHz RFR; 2 h/day for 90 days	0.003	Increased testosterone in blood; morphological changes in testis dependent on frequency
Ozorak et al. (2013)	Kidney and testis of rats exposed to 2450, 900, and 1800 MHz (217 Hz modulation) RFR; 1 h/day prenatal to 6 weeks of age	0.18	Increased lipid peroxidation in kidney and testis; decreased total antioxidant status, glutathione, glutathione peroxidase at 4th week postnatal; Decreased glutathione, total antioxidant status in kidney at 5th week; Increased lipid

			peroxidation, decreased total antioxidant status and glutathione in kidney and testis at 6th week.
Özyılmaz et al. (2024)	Thyroid of 6-month old offspring of pregnant rats exposed to 2450 MHz RFR, 24 h/day during pregnancy period	0.012	Morphological changes in mononuclear cell infiltration and vascular increase in congestion.
Özyılmaz et al. (2025)	Thyroid of 12-month old offspring of pregnant rats exposed to 2450 MHz RFR, 24 h/day during pregnancy period	0.012	Increases in fibrosis, atypical thyrocytes , and degenerated follicles, and colloid reduction. Increased apoptosis and double strand DNA breaks.
Pandey and Giri (2018)	Mice exposed to 900 MHz GSM RFR; 3 h twice/day for 35 days	0.0516	Testis showed morphological changes, increased DNA strand breaks and lower sperm count, and increased free radical formation, Effects attenuated by melatonin.
Pandey et al. (2017)	Mice exposed to 900-MHz RFR for 4 or 8 h per day for 35 days	0.0054-0.0516	DNA strand breaks in germ cells
Pavicic et al. (2006)	Chinese hamster V79 cells exposed to 864 and 935 MHz CW RFR, 1-3 h	864 MHz at 0.08 W/kg; 935 MHz at 0.12 W/kg	Cell growth affected
Pelletier et al. (2013)	Rat, 900 MHz, 23.4 h/day for 5 weeks	0.0001-0.0003	Induced energy saving process in body
Pérez-Castejón et al. (2009)	human astrocytoma cancer cells; 9600 MHz, 90% AM, 24 h	0.0004	Increase proliferation rate and connexin 43 expression

Perov et al. (2019)	Rats exposed to 171 MHz CW RFR, 6 h/day for15 days	0.006	Stimulation of adrenal gland activity
Persson et al. (1997)	Rats exposed to 915 MHz RFR -CW and pulse-modulated (217-Hz, 0.57 ms; 50-Hz, 6.6 ms) 2-960 min.	0.0004	Increase in permeability of the blood-brain barrier. CW more potent
Phillips et al. (1998)	Human leukemia cells exposed to 813.5625 MHz (iDEN); 836.55 MHz (TDMA) signals, 2 or 21 h	0.0024	DNA damage observed
Piccinetti et al. (2018)	Zebrafish exposed to 100 MHz RFR, 24-72 h post-fertilization	0.08	Retarded embryonic development
Porcher et al. (2023)	Leaves of Arabidopsis thaliana exposed to 2450 MHz RFR for 30 min	0.21	Increased H_2O_2
Postaci et al. (2018)	Rats exposed to 2600 MHz RFR, 1 h/day for 30 days	0.011	Cellular and oxidative damages in liver
Postaci et al. (2026)	Brain of rats exposed to 2600 MHz RFR, 1 h/day for 30 days	0.062	Increased apoptosis and BAX protein, decreased immune-positive cells.
Pyrpasopoulou et al. (2004)	Rats exposed to 9.4 GHz GSM (50 Hz pulses, 20 μs pulse length) signal, 1-7 days postcoitum	0.0005	Exposure during early gestation affected kidney development

Qin et al. (2014)	Rats exposed 1800 MHz RFR 2 h/day for 32 days	0.0405	Disruption of circadian rhythms, decreased testosterone levels, lower daily sperm production and sperm motility, down-regulated testis marker enzyme activity, and altered mRNA expression of cytochrome P450 and steroidogenic acute regulatory protein. Effect more pronounce at a certain time of the day.
Qin et al. (2018)	Mice exposed to 1800-MHz RFR, 2 h/day for 32 days	0.0553	Inhibition of testosterone synthesis
Qin et al. (2019)	Mouse Leydig cells exposed to 1800 MHz RFR; 1, 2, or 4 h	0.116	Down-regulation of testosterone synthase genes and clock genes.
Rafati et al. (2015)	Frog gastroenemius muscle exposed to cell phone jammers; 1 m away, 3 x 10 min periods	For different jammers: 0.01-0.05	Latency of contraction affected
Sagioglou et al. (2016)	Drosophila melanogaster exposed to 100, 395, 682, 900 MHz RFR for 6 or 60 min/day for 6 days post-hatching	0.00001-0.102	All exposure protocols resulted in an increase of apoptosis in egg chambers
Salford et al. (2003)	Rats exposed to 915 MHz GSM, 2 h	0.02	Nerve cell damage in brain
Sangun et al. (2015)	Rats exposed to 2450 MHz RFR during prenatal and postnatal periods; 1 h/day	0.143	Increased total oxidant status and oxidative stress index in brain and testis.
Sannino et al. (2014)	Human lymphocytes	0.3	A decrease in the number of micronuclei in

	exposed to 1950 MHz RFR for 20 h and then challenged with 1.0 or 1.5 Gy X-irradiation		lymphocytes exposed to RFR + x-ray as compared with those subjected to x-ray alone
Sarimov et al. (2004)	Human lymphocytes exposed to 895-915 MHz GSM signal, 30 min	0.0054	Chromatin affected similar to stress response.
Schwarz et al. (2008)	Human fibroblasts exposed to 1950 MHz UMTS signal, 24 h	0.05	Changes in genes.
Schwartz et al. (1990)	Frog hearts exposed to 240-MHZ RFR CW or sinusoidally modulated at 0.5 or 16 Hz for 30 min.	0.00015-0.003	Movement of calcium affected only with 16-Hz modulation at 0.003 and 0.00015 W/kg. No effect with CW and 0.5 Hz modulation.
Seewooruttun et al. (2025)	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.	0.07	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.
Sefidbakht et al. (2014)	HEK293T cell with firefly luciferease gene exposed to a 940 MHz RFR for 15-90 min	0.09	Endogenous luciferase activity was reduced after 30 and 45 min of continuous exposure, while after 60 min, the exposed cell lysate showed higher luciferase activity
Sepehrimanesh et al. (2014a)	Rats exposed to 900 MHz RFR for 1, 2, or 4 h/day for 30 days	0.19-1.22 (range of whole body SAR)	Disturbance in reproductive hormones

Sepehrimanesh et al. (2014b)	Rats exposed to 900 MHz RFR for 1, 2, or 4 h/day for 30 days	0.19-1.22	Changes in proteome, particularly in protein species in the testis
Sepehrimanesh et al. (2017)	Rats exposed to 900 MHz RFR for 1, 2, or 4 h/day for 30 days	0.19-1.22	Increases in testicular proteins in adults that are related to carcinogenic risk and reproductive damage
Shahin et al. (2013)	Mice exposed to 2450 MHz RFR, 2 h/day for 45 days	0.023	Increased DNA strand breaks in brain; decreased nitric oxide in blood; Increased reactive oxygen species, decreased superoxide dismutase, catalase. Glutathione peroxidase in liver, kidney, and Ovary
Shahin et al. (2014)	Mice exposed to 2450 MHz RFR; 2 h/day for 30 days	0.018	Decreased sperm count and viability, plasma testosterone; increased testicular nitric oxide synthase
Shahin and Singh (2018)	Mice exposed to 2450 MHz RFR; 2 h/day for 15, 30, or 60 days	0.0146	Induced redox imbalance and apoptosis in testis,
Sharma et al. (2017)	Brain of mice exposed to 10 GHz RFR 2 h/day for 15 days	0.179	Changes in oxidative enzymes, deficit in spatial memory, and histological changes in CA1 region of the hippocampus, cerebral cortex, and ansiform lobule of cerebellum. Effects persisted for at least 4 weeks.
Sharma and Shukla (2020)	Rats exposed to 900 MHz RFR for 1, 2, or 4 h/day for 90 days	Brain- 0.231	Increased DNA single strand breaks and increased oxidative stress in brain.

Sharma et al (2024)	Trigonella foenum-graecum L. seeds exposed to 2100 or 2300 MHz RFR for 0.5, 1,2 , 4, 8 h/day for 7 days	0.098	Increased chromosomal aberration, increased lipid peroxidation and antioxidant enzyme activities.
Singh et al. (2022)	Rats exposed to 1964.7 MHz RFR, 3 h/day, 5 days/week for 20 weeks	0.015	Protein deregulation in hippocampus
Sirav and Seyhan (2011)	Rats exposed to CW 900 MHz or 1800 MHz for 20 min	CW 900 MHz (0.00426 W/kg) or 1800 MHz (0.00146 W/kg)	Increased blood-brain barrier permeability in male rats, no significant effect on female rats
Sirav and Seyhan (2016)	Rats exposed to pulsed-modulated (217 Hz, 517 μs width) 900 MHz or 1800 MHz RFR for 20 min	0.02	In male rats, both frequencies increased blood-brain barrier permeability, 1800 MHz is more effective than 900 MHz; in female rats, only 900 MHz field caused an effect
Sokolovic et al. (2008)	Rats exposed to 900 MHz GSM RFR from a mobile phone; 4 h/day for 20, 40, or 60 days	0.043-0.135	Increased lipid peroxidation, protein oxidation; Decreased CAT, xanthine oxidase in brain
Sokolovic et al. (2013)	Rats exposed to 900 MHz GSM RFR from a mobile phone; 4 h/day for 20, 40, or 60 days	0.043-0.135	Increased lipid peroxidation, protein oxidation; Decreased CAT, xanthine oxidase; increased acid- and alkaline DNAse in thymus
Sokolovic et al. (2015)	Rats exposed to 900 MHz GSM RFR from a mobile phone; 4 h/day for 20, 40, or 60 days	0.043-0.135	Increased lipid peroxidation, protein oxidation, xanthine oxidase; decreased CAT in testis

Somosz et al. (1991)	Rat embryo 3T3 cells exposed to 2450-MHz 16-Hz square modulated RFR	0.024	Increased the ruffling activity of the cells, and caused ultrastructural alteration in the cytoplasm. CW was less effective
Spandole-Dinu et al. (2023)	Brain of mice exposed to 2450 MHz RFR with signal of a Wi-Fi router fed to an antenna for 16 weeks	0.01786	Brain global DNA methylation was lower in exposed mice.
Stagg et al. (1997)	Glioma cells exposed to 836.55 MHz TDMA signal, duty cycle 33%, 24 h	0.0059	Glioma cells showed significant increases in thymidine incorporation, which may be an indication of an increase in cell division
Stankiewicz et al. (2006)	Human white blood cells exposed to 900 MHz GSM signal, 217 Hz pulses-.577 ms width, 15 min	0.024	Immune activities of human white blood cells affected.
Stasinopoulou et al. (2016)	Rats exposed to wireless 1880-1900MHz Digital Enhanced Communication Telephony (DECT) base radiation; 12 h/day during pregnancy; offspring exposed for another 22 days	0.016-0.020	Pyramidal cell loss and glia fibrillary acidic protein (GFAP) over-expression were detected in the CA4 region of the hippocampus of the 22-day old pups.

Sueiro-Benavides et al. (2026)	RAW264.7 macrophages exposed to 2450 MHz RFR for 6, 24, or 48 h	0.174	Decreased cell viability (affecting apoptosis and narcosis) and increased lysosomal activity, interacted with lipopolysaccharide (LPS) and/or the SARS-CoV-2 spike protein.
Suhhova et al. (2013)	Human exposed to 450 MHz RFR modulated at 40 Hz (1 min ON/1 min OFF), 10 min each for 10 cycles	0.003	Affected alpha, beta 1 and beta 2 bands of resting EEG in 20% of subjects; effects were intensity-dependent
Sun Y. et al. (2017)	Human HL-60 cells exposed to 900 Hz RFR, 4 h/day for 5 days	peak and average SAR 4.1 x 10^{-4} and 2.5 x 10^{-4} W/kg	Increased oxidative DNA damage and reactive oxygen species; decreased mitochondrial gene expression
Syed Taha et al. (2026)	Rats exposed to 3.5 GHz or 24 GHz RFR for 1 h or 7 h/day for 60 days	3.5 GHz - 0.06; 24 GHz- 1.8x 10^{-7}	Changes in heat-shock protein expression (HSP27, HSP70, HSP90)
Szymanski et al. (2020)	Human blood mononucleus cells exposed to pulse-modulated 900 MHz RFR, two 15-min exposure	0.024	Cells demonstrated high immunological activity of monocytes and T-cell response to concanavalin A
Tahir et al. (2024)	Pregnant rats exposed to 2450 MHz RFR during pregnancy and offspring for 45 days after birth (1 h/day)	Cochlear SAR showing effects: 0.0023-0.032	Inner ear damage and apoptosis in cochlea of offspring.

Tan et al. (2022)	Rats exposed to 2450 MHz RFR; 12 h/day; starting one month before fertilization to the offspring were two months old. Exposure continues for 4 generations.	Adult: whole body 0.186, thymus 0.068; offspring: whole body 0.287, thymus 0.116	The number of offspring and mass of all rats decreased in the third-generation group. Vascularization was observed in the thymus of the fourth-generation offspring.
Tang et al. (2015)	Rats exposed to 900 MHz RFR, 3 h/day for 14-28 days	0.016	Spatial long-term memory deficit
Tas et al. (2014)	Rats exposed to 900 MHz RFR; 3 h/day for 1 year	0.0623	RFR altered some morphological parameters in the testis.
Tattersall et al. (2001)	Rat hippocampus, 700 MHz, 5-15 min	0.0016	Changes in hippocampal functions
Tkalec et al. (2013)	Earthworm exposed to continuous-wave and AM-modulated 900-MHz RFR for 2 - 4 h	0.00013, 0.00035, 0.0011, and 0.00933	Increased DNA strand breaks
Tomruk et al. (2022)	Rabbits exposed to 1800 MHz GSM signal; 15 min/day for 7 days during pregnancy (15^{th} to 22^{nd} day)	0.002	Cellular reactive oxygen species- dependent disturbances in metabolic activity in liver of offspring.
Topal et al. (2015)	Pregnant rats exposed to 900 MHz RFR; 1 h/day during days 13-21 of pregnancy	0.027	Induced oxidative stress and pathological alterations in the liver in the offspring.
Tripathi et al. (2023)	Rats exposed to 1760 MHz RFR; 2 h/day for 8 weeks	0.18	Disrupted insulin receptor signals, mitochondrial activity, and the antioxidant defense system

			in the hypothalamus and liver.
Trosić and Pavicić (2009)	Chinese hamster V79 cells exposed to 935 MHz RFR for 1-3 h	0.12	Declined proliferation and microtubule structure disruption observed
Tsoy et al. (2019)	Human and rat primary astrocytes exposed to 918 MHz RFR pulsed (0.58 ms) AM at 217 Hz; 24 h	0.2	Decreased β-amyloid-induced oxidative stress
Tsybulin et al. (2013)	Japanese Quail embryos exposed to GSM 900 MHz signal, 48 sec on/12 sec off; 38 or 158 h	0.003	Decreased DNA strand break at 38 h and increased in 158 h exposure in cells.
Türedi et al. (2015)	Pregnant rats exposed to 900 MHz RFR; 1 h/day on days 13-21 of pregnancy	0.025	Oxidative stress and histopathological changes in male rat offspring heart tissue detected.
Türedi et al. (2016)	Pregnant rats exposed to 900 MHz RFR; 1 h/day on days 13-21 of pregnancy	0.01	Decrease in ovarian follicle reservoirs in female offspring at the beginning of the prepubertal period.
Türedi et al. (2017)	Kidney and bladder of rats exposed to 900 MHz RFR; 1 h/day from 22-59 days of age	0.0067	Increased lipid peroxidation; decreased catalase and glutathione.
Upadhyaya et al. (2022)	Tomato plants exposed to 1800 MHz RFR up 12-120 h	0.0316 (leaves); 0.15 (fruits)	Decreased total antioxidant activities and other chemicals.

Vafaei et al. (2020)	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 delivery	0.09 at 30 cm	Increased gene expression of SOD, and GDKN1A, and GADD45a (DNA repair enzymes)
Velizarov et al. (1999)	Human epithelial amnion cells exposed to 960 MHz GSM signal, 217 Hz square-pulse, duty cycle 12%, 30 min	0.000021	Decreased proliferation
Veyret et al. (1991)	Mice exposed to 9.4 GHz 1 μs pulses at 1000 pps, also with or without sinusoidal AM between 14 and 41 MHz; 10 h/day for 5 days. Response only with AM modulation, direction of response depended on AM frequency	0.015	Changes in functions of the mouse immune system.
Wang S et al. (2025)	Mice exposed to 2450 MHz RFR, 3 h/day for 8 weeks; testes studied.	0.3	Decreased SOD, CAT, GSH; increased LPO and 8OHdG; morphological changes in spermatozoa

Wang XW et al. (2010)	Mice exposed to 200 electromagnetic pulses	average SAR 0.00004	Blood-testis barrier injury detected.
Wang Y et al. (2022)	Mating Drosophilia melanogaster exposed to 3500 MHz RFR for three days.	0.0026, 0.026, and 0.26	Enhanced pupae development observed at 0.0026 W/kg
Wang Y et al. (2025)	Male Drosophilia melanogaster exposed to 3500 MHz RFR for whole lifetime	0.0026, 0.026, and 0.26	Decreased ROS and CAT at 0.026 W/kg
Wen et al. (2021)	Mouse bone marrow stromal cells exposed to 900 MHz RFR; 4 h/day for 5 days	Peak and average SAR 4.1×10^{-4} and 2.5×10^{-4} W/kg, respectively	Increased reactive oxygen species at 30 min and 4 h post-exposure (normal at 24 h)
Wolke et al. (1996)	Isolated guinea pig heart muscle cells exposed to 900, 1300, 1800 MHz, square-wave modulated at 217 Hz; Also 900 MHz with CW, 16 Hz, 50 Hz and 30 KHz modulations, 500 sec	0.001	Changed calcium concentration in heart muscle cells
Xie et al. (2021)	Mouse bone marrow stem cells; CW 900 MHz RFR; 4 h/day for 5 days	Peak 4.1×10^{-4}; average 2.5×10^{-4}	Increased reactive oxygen species free radicals; induced mitochondrial unfolded protein.

Xu et al. (2020)	Mice exposed to 1800 MHz RFR; 2 h/day for 7 days	0.2986	Decreased sperm motility and increased sperm deformity rate; decreased the antioxidant enzymes activities of G6 PDH, ACP and CAT, and increased lipid peroxidation in testicular tissue
Yavas et al (2024)	Rats exposed to 2100 MHz RFR, 5 h/day for 14 days	0.292	Decreased Bax, increased bcl-2 gene expression, increased double strand DNA breaks in brain tissue
Yilmaz et al. (2017)	Pregnant rats exposed to 900 MHz RFR; 24 h/day for 20 days	0.087	Histological damage and changes in oxidative chemicals in liver of offspring at 60 days old.
Yilmaz et al. (2025)	Rats exposed to 5.9 GHz RFR 2 h/day or 30 days	0.0213	Histological damage and changes in oxidative chemicals in spermatozoa and testis.
Yilmaz et al. (2026)	Rats exposed to 5.9 GHz RFR 2 h/day or 30 days	0.0213	Histological damage and changes in oxidative chemicals in olfactory bulb.
Yüksel et al. (2016)	Pregnant rats and offspring exposed to 900, 1800, or 2450 MHz RFR; 60 min/day during pregnancy and growth (experiment over 4 generation)	0.1	Decreased plasma prolactin, progesterone, and estrogen levels, and increased uterine oxidative stress in pregnant rats and their offspring.
Yurekli et al. (2006)	Rats exposed to 945 MHz GSM, 217 Hz pulse-modulation 7 h/day for 8 days	0.0113	Changes in free radical chemistry

Zeni et al. (2012)	Human blood lymphocytes exposed to 1950 MHz UMTS RFR for 20 h at 1.25, 0.6, 0.3, or 0.15 W/kg, and treated with mitomycin C	0.3	RFR at 0.3 W/kg reduced micronucleus formation induced by mitomycin C.
Zong et al. (2015)	Mice exposed to 900 MHz RFR, 4 h/day for 7 days	0.05	Attenuated bleomycin-induced DNA breaks and repair
Zosangzuali et al. (2021)	Brain, heart, kidney and liver of mice exposed to 1800 MHz RFR (12 m from a mobile phone base station); 6, 12, or 24 h/day for 45 days	0.013	Decreased glutathione, glutathione S-transferase, and superoxide dismutase, increased lipid peroxidation in brain at 12 and 24 h/day exposure; no effect on heart, kidney and liver

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SAR <0.4 W/kg

0.29, 0.09, 0.000141, 0.048, 0.3957, 0.002647, 0.03, 0.25, 0.091, 0.06, 0.143, 0.018, 0.00004, 0.024, 0.323, 0.026, 0.037, 0.171, 0.02669, 0.037, 0.037, 0.0233, 0.0014, 0.00036, 0.028, 0.07, 0.08, 0.00013, 0.087, 0.000003, 0.00588, 0.00208, 0.23, 0.00155, 0.05653, 0.0608, 0.07, 0.23, 0.15, 0.064, 0.313, 0.282, 0.03561, 0.14, 0.2221, 0.00421, 0.117, 0.14, 0.00242, 0.03, 0.001, 0.015, 0.0006, 0.0000847, 0.0006, 0.0006, 0.008, 0.089, 0.004, 0.05, 0.005, 0.05, 0.00012, 0.3, 0.06, 0.14, 0.083, 0.107, 0.27, 0.22, 0.15, 0.21, 0.001, 0.018, 0.01, 0.0005, 0.0625, 0.07, 0.03825, 0.000052, 0.0053, 0.00072, 0.16, 0.04, 0.018, 0.0616, 0.02, 0.0026, 0.0265, 0.025, 0.0067, 0.0063, 0.02, 0.00025, 0.00025, 0.27, 0.04, 0.026, 0.06, 0.375, 0.09, 0.3, 0.2, 0.00051, 0.054, 0.0347, 0.012, 0.01, 0.0093, 0.0093, 0.0093, 0.0093, 0.0008, 0.0008, 0.11, 0.11, 0.26, 0.26, 0.067, 0.014, 0.014, 0.014, 0.014, 0.014, 0.014, 0.169, 0.092, 0.000584, 0.1, 0.143, 0.23, 0.0021, 0.19, 0.08, 0.12, 0.12, 0.0367, 0.0842, 0.03, 0.1, 0.009, 0.15, 0.037, 0.037, 0.0035, 0.14, 0.00058, 0.00058, 0.00066, 0.05, 0.046, 0.245, 0.36, 0.0027, 0.1434, 0.11, 0.1, 0.013, 0.0006, 0.025, 0.024, 0.024, 0.0098, 0.0096, 0.1, 0.0035, 0.016, 0.016, 0.38, 0.003, 0.18, 0.012, 0.012, 0.0516, 0.0054, 0.08, 0.0001, 0.0004, 0.006, 0.0004, 0.0024, 0.08, 0.21, 0.011, 0.062, 0.0005, 0.0405, 0.0553, 0.116, 0.01, 0.00001, 0.02, 0.143, 0.3, 0.0054, 0.05, 0.00015, 0.07, 0.09, 0.19, 0.19, 0.19, 0.023, 0.018, 0.0146, 0.179, 0.231, 0.098, 0.015, 0.00146, 0.02, 0.135, 0.135, 0.135, 0.024, 0.01786, 0.0059, 0.024, 0.016, 0.174, 0.003, 0.00025, 0.06, 0.024, 0.0023, 0.068, 0.016, 0.0623, 0.0016, 0.00013, 0.002, 0.027, 0.18, 0.12, 0.2, 0.003, 0.025, 0.01, 0.0067, 0.0316, 0.09, 0.000021, 0.015, 0.3, 0.00004, 0.0026, 0.026, 0.00025, 0.001, 0.00025, 0.2986, 0.292, 0.087, 0.0213, 0.0213, 0.1, 0.0113, 0.3, 0.05, 0.013

Mean= 0.072 W/kg; median = 0.028 W/kg, n=260 (range: 0.00003- 0.3951)

SAR < 0.08 W/kg

0.000141, 0.048, 0.002647, 0.03, 0.018, 0.00004, 0.024, 0.026, 0.037, 0.02669, 0.037, 0.037, 0.0233, 0.0014, 0.00036, 0.028, 0.07, 0.08, 0.00013, 0.000003, 0.00588, 0.00208, 0.00155, 0.05653, 0.0608, 0.07, 0.064, 0.03561, 0.00421, 0.00242, 0.03, 0.001, 0.015, 0.0006, 0.0000847, 0.0006, 0.0006, 0.008, 0.004, 0.05, 0.005, 0.05, 0.00012, 0.06, 0.001, 0.018, 0.01, 0.0005, 0.0625, 0.07, 0.03825, 0.000052, 0.0053, 0.00073, 0.04, 0.018, 0.0616, 0.02, 0.0026, 0.0265, 0.025, 0.0067, 0.0063, 0.02, 0.00025, 0.00025, 0.04, 0.026, 0.06, 0.00051, 0.054, 0.0347, 0.012, 0.01, 0.0093, 0.0093, 0.0093, 0.0093, 0.0008, 0.0008, 0.067, 0.014, 0.014, 0.014, 0.014, 0.014, 0.014, 0.000584, 0.0021, 0.08, 0.0367, 0.03, 0.009, 0.037, 0.037, 0.0035, 0.00058, 0.00058, 0.00066, 0.05, 0.046, 0.0027, 0.013, 0.0006, 0.025, 0.024, 0.024, 0.0098, 0.0096, 0.0035, 0.016, 0.016, 0.003, 0.012, 0.012, 0.0516, 0.0054, 0.0001, 0.0004, 0.006, 0.0004, 0.0024, 0.011, 0.062, 0.0005, 0.0405, 0.0553, 0.01, 0.00001, 0.02, 0.0054, 0.05, 0.00015, 0.023, 0.018, 0.0146, 0.015, 0.00146, 0.02, 0.024, 0.01786, 0.0059, 0.024, 0.016, 0.003, 0.00025, 0.06, 0.024, 0.0023, 0.068, 0.016, 0.0623, 0.0016, 0.00013, 0.002, 0.027, 0.003, 0.025, 0.01, 0.0067, 0.0316, 0.07, 0.000021, 0.015, 0.00004, 0.0026, 0.026, 0.00025, 0.001, 0.00025, 0.0213, 0.0213, 0.05, 0.013

Mean= 0.020 W/kg; median= 0.014 W/kg; n= 174 (range: 0.000003-0.08)

References with abstract

Adey WR, Bawin SM, Lawrence AF. Effects of weak amplitude-modulated microwave fields on calcium efflux from awake cat cerebral cortex. Bioelectromagnetics 3(3):295-307, 1982.

Calcium (45Ca2+) efflux was studied from preloaded cortex in cats immobilized under local anesthesia, and exposed to a 3.0-mW/cm2 450-MHz field, sinusoidally amplitude modulated at 16 Hz modulation depth 85%). Tissue dosimetry showed a field of 33 V/m in the interhemispheric fissure (rate of energy deposition 0.29 W/kg). Field exposure lasted 60 min. By comparison with controls, efflux curves from field exposed brains were disrupted by waves of increased 45Ca2+ efflux. These waves were irregular in amplitude and duration, but many exhibited periods of 20-30 min. They continued into the postexposure period. Binomial probability analysis indicates that the field-exposed efflux curves constitute a different population from controls at a confidence level of 0.96. In about 70% of cases, initiation of field exposure was followed by increased end-tidal CO2 excretion for about 5 min. However, hypercapnea induced by hypoventilation did not elicit increased 45Ca2+ efflux. Thus this increase with exposure does not appear to arise as a secondary effect of raised cerebral CO2 levels. Radioactivity measurements in cortical samples after superfusion showed 45Ca2+ penetration at about 1.7 mm/hr, consistent with diffusion of the ion in free solution.

Aitken, R.J., Bennett, L.E., Sawyer, D., Wiklendt, A.M., King, B.V. Impact of radio frequency electromagnetic radiation on DNA integrity in the male germline. Inter J Androl 28:171-179, 2005.

Concern has arisen over human exposures to radio frequency electromagnetic radiation (RFEMR), including a recent report indicating that regular mobile phone use can negatively impact upon human semen quality. These effects would be particularly serious if the biological effects of RFEMR included the induction of DNA damage in male germ cells. In this study, mice were exposed to 900 MHz RFEMR at a specific absorption rate of approximately 90 mW/kg inside a waveguide for 7 days at 12 h per day. Following exposure, DNA damage to caudal epididymal spermatozoa was assessed by quantitative PCR (QPCR) as well as alkaline and pulsed-field gel electrophoresis. The treated mice were overtly normal and all assessment criteria, including sperm number, morphology and vitality were not significantly affected. Gel electrophoresis revealed no gross evidence of increased single- or double-DNA strand breakage in spermatozoa taken from treated animals. However, a detailed analysis of DNA integrity using QPCR revealed statistically significant damage to both the mitochondrial genome ($p < 0.05$) and the nuclear beta-globin locus ($p < 0.01$). This study suggests that while RFEMR does not have a dramatic impact on male germ cell development, a significant genotoxic effect on epididymal spermatozoa is evident and deserves further investigation.

Akdag, M.Z., Dasdag, S., Canturk, F., Karabulut, D, Caner, Y, Adalier, N. Does prolonged radiofrequency radiation emitted from Wi-Fi devices induce DNA damage in various tissues of rats? J Chem Neuroanat. 75(Pt B):116-122, 2016.

Wireless internet (Wi-Fi) providers have become essential in our daily lives, as wireless technology is evolving at a dizzying pace. Although there are different frequency generators, one of the most commonly used Wi-Fi devices are 2.4GHz frequency generators. These devices are heavily used in all areas of life but the effect of radiofrequency (RF) radiation emission on users is generally ignored. Yet, an increasing share of the public expresses concern on this issue. Therefore, this study intends to respond to the growing public concern. The purpose of this study is to reveal whether long term exposure of 2.4GHz frequency RF radiation will cause DNA damage of different tissues such as brain, kidney, liver, and skin tissue and testicular tissues of rats. The study was conducted on 16 adult male Wistar-Albino rats. The rats in the experimental group (n=8) were exposed to 2.4GHz frequency radiation for over a year. The rats in the sham control group (n=8) were subjected to the same experimental conditions except the Wi-Fi generator was turned off. After the exposure period was complete the possible DNA damage on the rat's brain, liver, kidney, skin, and testicular tissues was detected through the single cell gel electrophoresis assay (comet) method. The amount of DNA damage was measured as percentage tail DNA value. Based on the DNA damage results determined by the single cell gel electrophoresis (Comet) method, it was found that the% tail DNA values of the brain, kidney, liver, and skin tissues of the rats in the experimental group increased more than those in the control group. The increase of the DNA damage in all tissues was not significant ($p>0.05$). However the increase of the DNA damage in rat testes tissue was significant ($p<0.01$). In conclusion, long-term exposure to 2.4GHz RF radiation (Wi-Fi) does not cause DNA damage of the organs investigated in this study except testes. The results of this study indicated that testes are more sensitive organ to RF radiation.

Alchalabi ASH, Aklilu E, Aziz AR, Malek F, Ronald SH, Khan MA. Different periods of intrauterine exposure to electromagnetic field: Influence on female rats' fertility, prenatal and postnatal development. Asian Pacific Journal of Reproduction 5: 14-23, 2016.

To assess the intrauterine irradiation of 1 800 MHz Global System of Mobile telecommunication on pre- and postnatal development in Sprague–Dawley rats. Methods: The whole-body irradiation 1 h/day and 2 h/day was applied to the pregnant rats in three different intervals (one week, two weeks and three weeks) at SAR 0.048 W/ Kg and control groups. Post-Morton findings and growth markers were monitored. Sera were collected for biochemical analysis. Results: Prenatal development findings showed uterine congestion, haemorrhage, dead and reabsorbed fetuses were observed in exposure groups during 2nd and 3rd week of pregnancy unlike to control. 1st and 2nd week in-utero irradiation showed significant reduction with unequal and asymmetrical distribution of implantation sites and embryos in exposure groups except the control group. A number of live embryos were significantly reduced with an increasing number of dead and reabsorbed embryos in the 2 h/day of the 2nd-week exposure group in compared to control group. Malformation, haematoma, and oedematous foetuses in experimental groups were observed unlike control foetuses. A

significant decrease in live foetuses and a significant decrease in body mass of foetuses at gestation day 20, unlike control group. Postnatal observations showed haematoma, congestion, short tail, malformation and growth restriction and delay in some growth markers were observed. In-utero irradiation for 2 and three weeks induced oxidative stress in pregnant rats. Conclusion: Results suggest that long-term exposure to EMF during the pregnancy lead to chronic stress, which has detrimental effects on pre-& postnatal development and for that more studies to clarify such harmful effects are recommended.

Alkis, M.S., Bilgin, H.M., Akpolat, V., Dasdag, S., Yegin, K., Yavas, M.C., Akdag, M.Z. Effect of 900-, 1800-, and 2100-MHz radiofrequency radiation on DNA and oxidative stress in brain. Electromagn Biol Med. 38:32-47, 2019a.

Ubiquitous and ever increasing use of mobile phones led to the growing concern about the effects of radiofrequency radiation (RFR) emitted by cell phones on biological systems. The aim of this study is to explore whether long-term RFR exposure at different frequencies affects DNA damage and oxidant-antioxidant parameters in the blood and brain tissue of rats. 28 male Sprague Dawley rats were randomly divided into four equal groups (n = 7). They were identified as Group 1: sham-control, Group 2: 900 MHz, Group 3: 1800 MHz, and Group 4: 2100 MHz. Experimental groups of rats were exposed to RFR 2 h/day for 6 months. The sham-control group of rats was subjected to the same experimental condition but generator was turned off. Specific absorption rates (SARs) at brain with 1 g average were calculated as 0.0845 W/kg, 0.04563 W/kg, and 0.03957, at 900 MHz, 1800 MHz, and 2100 MHz, respectively. Additionally, malondialdehyde (MDA), 8-hydroxydeoxyguanosine (8-OHdG), total antioxidant status (TAS), and total oxidant status (TOS) analyses were conducted in the brain tissue samples. Results of the study showed that DNA damage and oxidative stress indicators were found higher in the RFR exposure groups than in the sham-control group. In conclusion, 900-, 1800-, and 2100-MHz RFR emitted from mobile phones may cause oxidative damage, induce increase in lipid peroxidation, and increase oxidative DNA damage formation in the frontal lobe of the rat brain tissues. Furthermore, 2100-MHz RFR may cause formation of DNA single-strand breaks.

Alkis, M.S., Akdag, M.Z., Dasdag, S., Yegin, K., Akpolat, V. Single-strand DNA breaks and oxidative changes in rat testes exposed to radiofrequency radiation emitted from cellular phones. Biotech Biotech Equip. 33:1, 1733-1740, 2019b.

The testes are a sensitive organ to electromagnetic pollution and people are concerned about the harmful effects of the radiofrequency radiation (RFR) emitted from cellular phones. Therefore, the purpose of this study was to investigate the effects of long-term exposure to different RFR frequencies on single-strand DNA breaks and oxidative changes in rat testicular tissue. Twenty-eight male Sprague–Dawley rats were divided randomly into four groups. Three groups were exposed to radiation emitted from 900, 1800 and 2100 MHz RF generators, 2 h/day for 6 months. The sham-control group was kept under the same experimental conditions but the RFR generator was turned off. Immediately after the last exposure, testes were removed and DNA damage, 8-hydroxydeoxyguanosine (8-OHdG), malondialdehyde (MDA), total antioxidant status (TAS), total oxidant status (TOS) and oxidative stress index (OSI) were analyzed. The results of this study indicated that RFR increased TOS, OSI, MDA and 8-OHdG ($p < 0.05$). TAS levels in the exposed group were lower than in the sham group ($p < 0.05$). In terms of DNA damage, the

tail intensities in the comet assay were higher in the exposure groups ($p < 0.05$). This study demonstrated that long-term exposure to RFR emitted by cellular phones may cause oxidative stress and oxidative DNA damage in rat testicular tissue and may generate DNA single-strand breaks at high frequencies (1800 and 2100 MHz). Our results showed that some RFR emitted from cellular phones has potential to lead to cell damage in the testes.

Amiri H, Shabkhiz F, Pournemati P, Quchan AHSK, Fard RZ. Swimming exercise reduces oxidative stress and liver damage indices of male rats exposed to electromagnetic radiation. Life Sci 317:121461, 2023.

Objectives: Hepatic damage caused by oxidative stress is one of the problems associated with the emission of electromagnetic radiation (EMR). In this study, the effects of swimming exercise (SE) on oxidative stress and liver cell damage caused by EMR emission in rats were investigated. **Methods:** Thirty-two rats (8 weeks old) were randomly divided into four groups, including control (C), EMR, SE, and EMR + SE. During four weeks, the animals engaged in SE (30 min/session, 5 session/week) and were also exposed to EMR (4 h/day, seven days/week) emission from a Wi-Fi 2.45 GHZ router. The liver and blood samples were collected at 48 h after completing four weeks of SE to assess histopathological damage, oxidative stress, and liver enzymes. **Key findings:** Tissue sections showed severe liver damage in the EMR group compared to the C group, while the SE attenuated the liver damage. In the EMR group, compared to the C, SE and EMR + SE groups, the activity of superoxide dismutase (SOD) and catalase (CAT) decreased significantly, and the concentration of malondialdehyde (MDA) and liver enzymes (AST, ALT, and ALP) increased significantly ($P < 0.05$). Swimming exercise in the SE and EMR + SE groups compared to EMR led to a significant increase in the activity of SOD and CAT and a significant decrease in the concentration of MDA and liver enzymes ($P < 0.05$). **Conclusion:** The study findings showed that the SE is beneficial in attenuating the harmful effects of RF-EMR emitted from the Wi-Fi on the liver.

Arendash, G.W., Sanchez-Ramos, J., Mori, T., Mamcarz, M., Lin, X., Runfeldt, M., Wang, L., Zhang, G., Sava, V., Tan, J., Cao, C. Electromagnetic field treatment protects against and reverses cognitive impairment in Alzheimer's disease mice. J Alzheimers Dis. 19:191-210, 2010.

Despite numerous studies, there is no definitive evidence that high-frequency electromagnetic field (EMF) exposure is a risk to human health. To the contrary, this report presents the first evidence that long-term EMF exposure directly associated with cell phone use (918 MHz; 0.25 w/kg) provides cognitive benefits. Both cognitive-protective and cognitive-enhancing effects of EMF exposure were discovered for both normal mice and transgenic mice destined to develop Alzheimer's-like cognitive impairment. The cognitive interference task utilized in this study was designed from, and measure-for-measure analogous to, a human cognitive interference task. In Alzheimer's disease mice, long-term EMF exposure reduced brain amyloid-beta (Abeta) deposition through Abeta anti-aggregation actions and increased brain temperature during exposure periods. Several inter-related mechanisms of EMF action are proposed, including increased Abeta clearance from the brains of Alzheimer's disease mice, increased neuronal activity, and increased cerebral blood flow. Although caution should be taken in extrapolating these mouse studies to humans, we conclude that EMF exposure may represent a non-invasive,

non-pharmacologic therapeutic against Alzheimer's disease and an effective memory-enhancing approach in general.

Arslan B, Aras N, Yaman S, Comelekoglu U. Investigation of genetic stress parameters in brain tissues of rats exposed to 1.8 GHz cell phone radiofrequency electromagnetic field. Med Science. 13(1):78-82, 2024.

Heat Shock Proteins (HSPs) may induce various cellular processes, including replication, apoptosis, cell-cycle progression. Mitogen-activated protein kinase (MAPK) cascades are the primary mechanism that mediates the cellular stress response to extracellular stimuli and regulates transcriptional activity. It has been shown that mobile phone exposure can stimulate the Hsp27/p38MAPK stress pathway. In this study, twenty-seven mature female Wistar albino rats were exposed to 1.8 GHz radiofrequency electromagnetic field (RF-EMF) 2h/day for 8 weeks (SAR: 0.06 W/kg). Hsp27 and p38MAPK gene expressions were investigated in rat brains. Rats were divided into groups sham-exposed, cage control, and 1.8 GHz RF-EMF exposed. Hsp27 and p38MAPK gene expression levels were investigated from the brain. p38MAPK expression was found to be upregulated in RF-EMF exposed group ($p=0.018$) Hsp27 expressions were not altered ($p=0.897$). In conclusion, long-term exposure to 1.8 GHz cell phone radiation can activate the Hsp27/p38MAPK stress pathway. It may cause several cellular disorders and can affect brain function.

Atasoy, H.I., Gunal, M.Y., Atasoy, P., Elgun, S., Bugdayci, G. Immunohistopathologic demonstration of deleterious effects on growing rat testes of radiofrequency waves emitted from conventional Wi-Fi devices. J Pediatr Urol. 9:223-229, 2013.

Objective: To investigate effects on rat testes of radiofrequency radiation emitted from indoor Wi-Fi Internet access devices using 802.11.g wireless standards. **Methods:** Ten Wistar albino male rats were divided into experimental and control groups, with five rats per group. Standard wireless gateways communicating at 2.437 GHz were used as radiofrequency wave sources. The experimental group was exposed to radiofrequency energy for 24 h a day for 20 weeks. The rats were sacrificed at the end of the study. Intracardiac blood was sampled for serum 8-hydroxy-2'-deoxyguanosine levels. Testes were removed and examined histologically and immunohistochemically. Testis tissues were analyzed for malondialdehyde levels and prooxidant-antioxidant enzyme activities. **Results:** We observed significant increases in serum 8-hydroxy-2'-deoxyguanosine levels and 8-hydroxyguanosine staining in the testes of the experimental group indicating DNA damage due to exposure ($p < 0.05$). We also found decreased levels of catalase and glutathione peroxidase activity in the experimental group, which may have been due to radiofrequency effects on enzyme activity ($p < 0.05$). **Conclusions:** These findings raise questions about the safety of radiofrequency exposure from Wi-Fi Internet access devices for growing organisms of reproductive age, with a potential effect on both fertility and the integrity of germ cells.

Aynali G, Nazıroğlu M, Celik O, Doğan M, Yarıktaş M, Yasan H. Modulation of wireless (2.45 GHz)-induced oxidative toxicity in laryngotracheal mucosa of rat by melatonin. Eur Arch Otorhinolaryngol. 270(5):1695-1700, 2013.

It is well known that oxidative stress induces larynx cancer, although antioxidants induce modulator role on etiology of the cancer. It is well known that electromagnetic radiation (EMR) induces oxidative stress in different cell systems. The aim of this study was to investigate the possible protective role of melatonin on oxidative stress induced by Wi-Fi (2.45 GHz) EMR in laryngotracheal mucosa of rat. For this purpose, 32 male rats were equally categorized into four groups, namely controls, sham controls, EMR-exposed rats, EMR-exposed rats treated with melatonin at a dose of 10 mg/kg/day. Except for the controls and sham controls, the animals were exposed to 2.45 GHz radiation during 60 min/day for 28 days. The lipid peroxidation levels were significantly ($p < 0.05$) higher in the radiation-exposed groups than in the control and sham control groups. The lipid peroxidation level in the irradiated animals treated with melatonin was significantly ($p < 0.01$) lower than in those that were only exposed to Wi-Fi radiation. The activity of glutathione peroxidase was lower in the irradiated-only group relative to control and sham control groups but its activity was significantly ($p < 0.05$) increased in the groups treated with melatonin. The reduced glutathione levels in the mucosa of rat did not change in the four groups. There is an apparent protective effect of melatonin on the Wi-Fi-induced oxidative stress in the laryngotracheal mucosa of rats by inhibition of free radical formation and support of the glutathione peroxidase antioxidant system.

Bakacak M, Bostancı MS, Attar R, Yıldırım ÖK, Yıldırım G, Bakacak Z, Sayar H, Han A. The effects of electromagnetic fields on the number of ovarian primordial follicles: An experimental study. Kaohsiung J Med Sci. 31(6):287-292, 2015.

The aim of this study was to evaluate the effect of an electromagnetic field (EMF), generated close to the ovaries, on primordial follicles. A total of 16 rats were used in this study. The study group consisted of rats exposed to an EMF in the abdominal region for 15 min/d for 15 days. Both the study and control group were composed of eight rats. After the treatment period of 15 days, the ovaries of the rats were extracted, and sections of ovarian tissue were taken for histological evaluation. The independent samples t test was used to compare the two groups. In the study group, the means of the right and left ovarian follicle numbers were 34.00 ± 10.20 and 36.00 ± 10.53, respectively. The average total ovarian follicle number was 70.00 ± 19.03. In the control group, the means of the right and left ovarian follicle numbers were 78.50 ± 25.98 and 71.75 ± 29.66, respectively, and the average total ovarian follicle number was 150.25 ± 49.53. The comparisons of the means of the right and left ovarian follicle numbers and the means of the total ovarian follicle numbers between the study and control groups indicated that the study group had significantly fewer follicles ($p < 0.001$, $p = 0.011$, and $p = 0.002$, respectively). This study found a significant decrease in the number of ovarian follicles in rats exposed to an EMF. Further clinical studies are needed to reveal the effects of EMFs on ovarian reserve and infertility.

Barteri M, De Carolis R, Marinelli F, Tomassetti G, Montemiglio LC. Effects of microwaves (900 MHz) on peroxidase systems: a comparison between lactoperoxidase and horseradish peroxidase. Electromagn Biol Med. 35(2):126-133, 2016.

This work shows the effects of exposure to an electromagnetic field at 900 MHz on the catalytic activity of the enzymes lactoperoxidase (LPO) and horseradish peroxidase (HRP). Experimental evidence that irradiation causes conformational changes of the active sites and influences the formation and stability of the intermediate free radicals is documented by measurements of enzyme kinetics, circular dichroism spectroscopy (CD) and cyclic voltammetry.

Bedir, R., Tumkaya, L., Mercantepe, T., Yilmaz, A. Pathological findings observed in the kidneys of postnatal male rats exposed to the 2100 MHz electromagnetic field. Arch Med Res. 49:432-440, 2018.

Background: The widespread use by young people of modern communication devices such as mobile phones means that they are particularly exposed to electromagnetic fields (EMF) and other problems. However, few studies have researched the effects of long-term exposure to EMF in the kidney. We therefore investigated oxidative stress and apoptosis in long-term exposure to 2100 megahertz (MHz) in a rat model. **Materials and methods:** Twenty-four Sprague Dawley rats were divided into a control group (n = 8, no EMF exposure), a group exposed to 2100 MHz for 6 h for 30 d (n = 8), and a group exposed to 2100 MHz for12 h for 30 d (n = 8). Immunohistochemical analysis was performed, using caspase-3 to evaluate apoptosis. Immediately after treatment, reduced glutathione (GSH), malondialdehyde (MDA) in kidney tissue and serum levels of various biochemical compounds were measured to detect oxidative stress. **Results:** Deterioration was observed in the brush border in renal tubules of the EMF groups. The results of the immunohistochemical analysis revealed a greater number of positively stained renal tubular epithelial cells in the EMF groups as compared with that in the control group. In the EMF groups, renal MDA levels increased, and renal GSH levels decreased compared with those in the control group, as shown by a biochemical examination ($p = 0.00$ and $p = 0.00$, respectively). **Conclusion:** The findings showed that exposure to 2100 MHz for 6 and 12 h induced oxidative stress-mediated acute renal injury, depending on the length of exposure and dosage.

Bektas H, Algul S, Altindag F, Yegin K, Akdag Z, Dasdag S. Effects of 3.5 GHz (5G) radiofrequency radiation on ghrelin, nesfatin-1, and irisin levels in diabetic and healthy brains. J Chem Neuroanat 126:102168, 2022.

Diabetes, mobile phone use, and obesity have increased simultaneously in recent years. The radiofrequency radiation (RFR) emitted from mobile phones is largely absorbed in the heads of users. With 5G, which has started to be used in some countries without the necessary precautions being taken, the amount of RFR to which living things are exposed will increase. In this study, the changes in energy homeostasis and redox balance caused by 5G (3.5GHz, GSM-modulated) were explored. The effects of RFR on the brains of diabetic and healthy rats were investigated and histopathological analysis was performed. Twenty-eight Wistar albino rats weighing 200-250g were divided into 4 groups as sham, RFR, diabetes, and RFR+diabetes groups (n=7). The rats in each group were kept in a plexiglass carousel for 2 hours a day for 30 days. While the rats in the experimental groups were exposed to RFR for 2 hours a day, the rats in the sham group were kept under the same experimental conditions but with the radiofrequency generator turned off. At the end of the experiment, brain tissues were collected from euthanized rats. Total antioxidant (TAS), total oxidant (TOS), hydrogen peroxide (H_2O_2), ghrelin, nesfatin-1, and irisin

levels were determined. In addition, histopathological analyses of the brain tissues were performed. The specific absorption rate in the grey matter of the brain was calculated as 323mW/kg and 195mW/kg for 1g and 10g averaging, respectively. After RFR exposure among diabetic and healthy rats, decreased TAS levels and increased TOS and H_2O_2 levels were observed in brain tissues. RFR caused increases in ghrelin and irisin and a decrease in nesfatin-1 in the brain. It was also observed that RFR increased the number of degenerated neurons in the hippocampus. Our results indicate that 5G RFR causes changes in the energy metabolism and appetite of both healthy and diabetic rats. Thus, 5G may not be innocent in terms of its biological effects, especially in the presence of diabetes.

Bektas H, Nalbant A, Akdag MB, Demir C, Kavak S, Dasdag S. Adverse effects of 900, 1800 and 2100 MHz radiofrequency radiation emitted from mobile phones on bone and skeletal muscle. Electromagn Biol Med 42(1):12-20, 2023.

The goal of this study was to biomechanically and morphologically research both the impact of mobile phone like radiofrequency radiations (RFR) on the tibia and the effects on skeletal muscle through oxidative stress parameters. Fifty-six rats (200-250 g) were put into groups: healthy sham (n = 7), healthy RFR (900, 1800, 2100 MHz) (n = 21), diabetic sham (n = 7) and diabetic RFR (900, 1800, 2100 MHz) (n = 21). Over a month, each group spent two hours/day in a Plexiglas carousel. The rats in the experimental group were exposed to RFR, but the sham groups were not. At the end of the experiment, the right tibia bones and skeletal muscle tissue were removed. The three-point bending test and radiological evaluations were performed on the bones, and CAT, GSH, MDA, and IMA in muscles were measured. There were differences in biomechanics properties and radiological evaluations between the groups ($p < .05$). In the measurements in the muscle tissues, significant differences were statistically found ($p < .05$). The average whole-body SAR values for GSM 900, 1800 and 2100 MHz were 0.026, 0.164, and 0.173 W/kg. RFRs emitted from mobile phone may cause adverse effects on tibia and skeletal muscle health, though further studies are needed.

Bektas H, Dasdag S, Altindag F, Akdag MZ, Yegin K, Algul S. Effects of 3.5-GHz radiofrequency radiation on energy-regulatory hormone levels in the blood and adipose tissue. Bioelectromagnetics 45(5):209-217, 2024.

In recent years exposure of living beings to radiofrequency radiation (RFR) emitted from wireless equipment has increased. In this study, we investigated the effects of 3.5-GHz RFR on hormones that regulate energy metabolism in the body. Twenty-eight rats were divided into four groups: healthy sham (n = 7), healthy RFR (n = 7), diabetic sham (n = 7), and diabetic RFR (n = 7). Over a month, each group spent 2 h/day in a Plexiglas carousel. The rats in the experimental group were exposed to RFR, but the sham groups were not. At the end of the experiment, blood and adipose tissues were collected from euthanized rats. Total antioxidant, total oxidant, hydrogen peroxide, ghrelin, nesfatin-1, and irisin were determined. Insulin expression in pancreatic tissues was examined by immunohistochemical analysis. Whole body specific absorption rate was 37 mW/kg. For the parameters analyzed in blood and fat, the estimated effect size varied within the ranges of 0.215-0.929 and 0.503-0.839, respectively. The blood and adipose nesfatin-1 ($p = 0.002$), blood and pancreatic insulin are decreased, ($p = 0.001$), gherelin

($p = 0.020$), irisin ($p = 0.020$), and blood glucose ($p = 0.040$) are increased in healthy and diabetic rats exposed to RFR. While nesfatin-1 are negatively correlated with oxidative stress, hyperglycemia and insulin, ghrelin and irisin are positively correlated with oxidative stress and hyperglycemia. Thus, RFR may have deleterious effects on energy metabolism, particularly in the presence of diabetes.

Bektas H, Seker A, Ustun R, Dogu S. Neurotoxic effects of 3.5 GHz GSM-like RF exposure on cultured DRG neurons: a mechanistic insight into oxidative and apoptotic pathways. Int J Radiat Biol. 2026a Jan 21:1-14. doi: 10.1080/09553002.2026.2617592. Epub ahead of print.

Purpose: This study investigated whether strictly non-thermal, GSM-like 3.5 GHz radiofrequency electromagnetic fields (RF-EMF)-overlapping in frequency with bands used by 5 G networks but not employing a 5 G NR waveform-disrupt redox homeostasis and activate apoptotic signaling in peripheral sensory neurons. **Materials and methods:** Primary mouse dorsal root ganglion (DRG) cultures were exposed in a GTEM-based setup to pulsed 3.5 GHz RF-EMF (217 Hz, ∼12.5% duty) for 1-24 h at 37 °C with <0.1 °C temperature difference between groups. Dosimetry confirmed non-thermal exposure with localized peaks consistent with IEEE/IEC guidance. Cell viability, reactive oxygen species (ROS), mitochondrial-apoptotic markers (Bax, Bcl-2, cytochrome c, caspase-3), and p75^NTR were quantified by blinded confocal analysis. **Results:** RF-EMF caused a significant, time-dependent reduction in viability with robust ROS elevations; increased Bax and caspase-3; decreased Bcl-2; and cytochrome c release, with maximal effects at 12-24 h. p75^NTR upregulation indicated maladaptive neurotrophin signaling. **Conclusions:** Under non-thermal conditions, 3.5 GHz RF-EMF perturbs redox balance and triggers mitochondria-dependent apoptosis in DRG neurons, highlighting peripheral neuronal vulnerability to mid-band exposures. These findings provide a mechanistic link between RF exposure and oxidative/apoptotic pathways and warrant in vivo studies assessing long-term and interventional outcomes.

Bektas H, Yildirim S, Cakir S, Dogu S, Altindag F. Ameliorative Role of Coenzyme Q10 in RF Radiation-Associated Testicular and Oxidative Impairments in a 3.5-GHz Exposure Model. Bioelectromagnetics. 47(1):e70043, 2026b.

This study investigated the biological effects of GSM-modulated 3.5 GHz radiofrequency (RF) electromagnetic field exposure on male reproductive function and evaluated the potential protective role of Coenzyme Q10 (CoQ10). Twenty-eight adult male Wistar rats were allocated into four groups: Control, RF, CoQ10, and RF + CoQ10. Animals were exposed to RF for 2 h/day over 30 days, while CoQ10 was administered intraperitoneally at 10 mg/kg/day. Hormonal (testosterone, LH, FSH), biochemical (MDA, GSH, TAS, TOS), and histopathological assessments were performed. Specific absorption rate (SAR) simulations estimated a whole-body SAR of 0.16995 W/kg and a testis-specific SAR of 0.02669 W/kg. RF exposure significantly reduced testosterone, LH, and FSH levels, increased MDA and TOS concentrations, and induced degenerative changes in testicular histology. CoQ10 treatment partially ameliorated these alterations by restoring testosterone and TAS levels and reducing tissue damage. These results indicate that even low-SAR GSM-modulated 3.5 GHz RF exposure may negatively impact male reproductive health, and CoQ10 supplementation may confer partial protective effects. Because

the exposure consisted of a GSM-modulated waveform, the results cannot be extrapolated to FR1 5G NR signals used in real communication systems. Further studies are needed to clarify mechanisms and assess biological relevance under real-world exposure conditions.

Belyaev, I.Y., Hillert, L., Protopopova, M., Tamm, C., Malmgren, L.O., Persson, B.R., Selivanova, G., Harms-Ringdahl, M. 915 MHz microwaves and 50 Hz magnetic field affect chromatin conformation and 53BP1 foci in human lymphocytes from hypersensitive and healthy persons. Bioelectromagnetics. 26:173-184, 2005.

We used exposure to microwaves from a global system for mobile communication (GSM) mobile phone (915 MHz, specific absorption rate (SAR) 37 mW/kg) and power frequency magnetic field (50 Hz, 15 muT peak value) to investigate the response of lymphocytes from healthy subjects and from persons reporting hypersensitivity to electromagnetic field (EMF). The hypersensitive and healthy donors were matched by gender and age and the data were analyzed blind to treatment condition. The changes in chromatin conformation were measured with the method of anomalous viscosity time dependencies (AVTD). 53BP1 protein, which has been shown to colocalize in foci with DNA double strand breaks (DSBs), was analyzed by immunostaining in situ. Exposure at room temperature to either 915 MHz or 50 Hz resulted in significant condensation of chromatin, shown as AVTD changes, which was similar to the effect of heat shock at 41 degrees C. No significant differences in responses between normal and hypersensitive subjects were detected. Neither 915 MHz nor 50 Hz exposure induced 53BP1 foci. On the contrary, a distinct decrease in background level of 53BP1 signaling was observed upon these exposures as well as after heat shock treatments. This decrease correlated with the AVTD data and may indicate decrease in accessibility of 53BP1 to antibodies because of stress-induced chromatin condensation. Apoptosis was determined by morphological changes and by apoptotic fragmentation of DNA as analyzed by pulsed-field gel electrophoresis (PFGE). No apoptosis was induced by exposure to 50 Hz and 915 MHz microwaves. In conclusion, 50 Hz magnetic field and 915 MHz microwaves under specified conditions of exposure induced comparable responses in lymphocytes from healthy and hypersensitive donors that were similar but not identical to stress response induced by heat shock.

Belyaev, I.Y., Markovà, E., Hillert, L., Malmgren, L.O., Persson, B.R. Microwaves from UMTS/GSM mobile phones induce long-lasting inhibition of 53BP1/gamma-H2AX DNA repair foci in human lymphocytes. Bioelectromagnetics. 30:129-141, 2009.

We have recently described frequency-dependent effects of mobile phone microwaves (MWs) of global system for mobile communication (GSM) on human lymphocytes from persons reporting hypersensitivity to electromagnetic fields and healthy persons. Contrary to GSM, universal global telecommunications system (UMTS) mobile phones emit wide-band MW signals. Hypothetically, UMTS MWs may result in higher biological effects compared to GSM signal because of eventual "effective" frequencies within the wideband. Here, we report for the first time that UMTS MWs affect chromatin and inhibit formation of DNA double-strand breaks co-localizing 53BP1/gamma-H2AX DNA repair foci in human lymphocytes from hypersensitive and healthy persons and confirm that effects of GSM MWs depend on carrier frequency. Remarkably, the effects of MWs on 53BP1/gamma-H2AX foci persisted up to 72 h following exposure of cells, even longer than the stress response following heat shock. The data are in line

with the hypothesis that the type of signal, UMTS MWs, may have higher biological efficiency and possibly larger health risk effects compared to GSM radiation emissions. No significant differences in effects between groups of healthy and hypersensitive subjects were observed, except for the effects of UMTS MWs and GSM-915 MHz MWs on the formation of the DNA repair foci, which were different for hypersensitive ($P < 0.02$[53BP1]//0.01[gamma-H2AX]) but not for control subjects ($P > 0.05$). The non-parametric statistics used here did not indicate specificity of the differences revealed between the effects of GSM and UMTS MWs on cells from hypersensitive subjects and more data are needed to study the nature of these differences.

Bilgici B, Gun S, Avci B, Akar A, Engiz BK. What is adverse effect of wireless local area network, using 2.45 GHz, on the reproductive system? Int J Radiat Biol 94(11):1054-1061, 2018.

Aim: To investigate the inflammatory effect and testicular damage on rats exposed to low level of electromagnetic fields (EMF) at 2.45 GHz microwave radiation. **Methods:** Twenty two Wistar rats were divided into two groups. Group 1 was the control group and not exposed to EMF. Group 2 was exposed to low level EMF (average E-field 3.68 ± 0.36 V/m, whole body average SAR, 0.0233 W/kg, in 10 g tissue) at 2.45 GHz for 1 hour/day for 30 consecutive days. At the end of the study, interleukin-6 (IL-6), interleukin-10 (IL-10), interleukin-32 (IL-32), C-reactive protein (CRP) were measured in rat serum and IL-6, IL-10, IL-32 were measured in rat testis tissue. Furthermore, testicular tissues were evaluated histopathologically in terms of spermatogenesis and coagulation necrosis. **Results:** Serum IL-6 and CRP levels were found to be significantly different in the study group compared to the control group ($p < .05$), but no significant difference was found in serum IL-10, IL-32 levels and testis tissue IL-6, IL-10, IL-32 levels compared to the control group ($p > .05$). On the other hand, histopathological evaluation of testicular tissue revealed a significant difference in necrosis and spermatogenesis when compared with the control group ($p < .05$). **Conclusions:** It may be concluded that low level EMF at 2.45 GHz increases inflammation and testicular damage and negative impact on male reproductive system function.

Blackman, C.F., Benane, S.G., Joines, W.T., Hollis, M.A., House, D.E. Calcium-ion efflux from brain tissue: power-density versus internal field-intensity dependencies at 50-MHz RF radiation. Bioelectromagnetics. 1: 277-283, 1980.

In previous experiments changes were found in calcium-ion efflux from chick-brain tissue that had been exposed in vitro to 147-MHz radiation across a specific range of power densities when the field was amplitude modulated at 16 Hz. In the present study, 50-MHz radiation, similarly modulated as a sinusoid, was found to produce changes in calcium-ion efflux from chick brains exposed in vitro in a Crawford cell. Exposure conditions were optimized to broaden any power-density window and to enhance the opportunity to detect changes in the calcium-ion efflux. The results of a power-density series demonstrated two effective ranges: One spanning a range from 1.44 to 1.67 mW/cm2, and the other including 3.64 mW/cm2, which were bracketed by no-effect results at 0.72, 2.17, and 4.32 mW/cm2. peaks of positive findings are associated with near-identical rates of energy absorption: 1.4 microW/g at 147 MHz, and 1.3 microW/g at 50 MHz, which indicates that the enhanced-efflux phenomenon is more dependent on the intensity of fields in the brain than on the power density of incident radiation. In addition, the phenomenon

appears to occur at multiples of some, as yet unknown, rate of radiofrequency (RF) energy absorption. Because of the extremely small increments of temperature associated with positive findings (less than 4 X 10(-4) degrees C), and the existence of more than one productive absorption rate, a solely thermal explanation appears extremely unlikely.

Blackman, C.F., Kinney, L.S., House, D.E., Joines, W.T. Multiple power-density windows and their possible origin. Bioelectromagnetics 10:115-128, 1989.

We have previously reported that in vitro exposure of chick forebrain tissue to 50-MHz radiofrequency (RF) electromagnetic radiation, amplitude modulated (AM) at 16 Hz, would enhance the efflux of calcium ions within only two power-density ranges: one from 1.44 to 1.67 mW/cm2, and the other including 3.64 mW/cm2. No effect on efflux occurred at 0.37, 0.72, 2.17, and 4.32 mW/cm2. We confirmed and extended these results by testing at another set of power densities, which included the range of the previous study. Forebrain tissue from 1-7-day-old chickens was labeled in vitro with radioactive calcium ions (30 min, at 37 degrees C), rinsed, placed in a physiological salt solution, and then exposed for 20 min to 50-MHz radiation, AM at 16 Hz, in a transverse electric and magnetic field (TEM) cell maintained at 37 degrees C. The solution was then assayed for radioactive calcium activity. A power-density series was tested. An enhanced efflux of calcium ions was found at 1.75, 3.85, 5.57, 6.82, 7.65, 7.77, and 8.82 mW/cm2; no change was observed at 0.75, 2.30, 4.50, 5.85, 7.08, 8.19, 8.66, 10.6, and 14.7 mW/cm2. Power density is converted to specific absorption rate (SAR) by 0.36 mW/kg per mW/cm2. Even the highest SAR tested (0.005 W/kg) is much too low to result in generalized heating of the sample and thus to be the underlying cause of the enhanced response. A hypothetical mechanism is proposed involving dynamic systems that may account for the power-density dependency as well as for part of the frequency dependency observed with both modulated RF radiation and extremely-low-frequency (ELF) fields.

Bodera P, Stankiewicz W, Antkowiak B, Paluch M, Kieliszek J, Sobiech J, Niemcewicz M. Influence of electromagnetic field (1800 MHz) on lipid peroxidation in brain, blood, liver and kidney in rats. Int J Occup Med Environ Health. 28(4):751-759, 2015.

OBJECTIVES: The aim of this study is the evaluation of the influence of repeated (5 times for 15 min) exposure to electromagnetic field (EMF) of 1800 MHz frequency on tissue lipid peroxidation (LPO) both in normal and inflammatory state, combined with analgesic treatment. MATERIAL AND METHODS: The concentration of malondialdehyde (MDA) as the end-product of the lipid peroxidation (LPO) was estimated in blood, liver, kidneys, and brain of Wistar rats, both healthy and those with complete Freund's adjuvant (CFA)-induced persistent paw inflammation. RESULTS: The slightly elevated levels of the MDA in blood, kidney, and brain were observed among healthy rats in electromagnetic field (EMF)-exposed groups, treated with tramadol (TRAM/EMF and exposed to the EMF). The malondialdehyde remained at the same level in the liver in all investigated groups: the control group (CON), the exposed group (EMF), treated with tramadol (TRAM) as well as exposed to and treated with tramadol (TRAM/EMF). In the group of animals treated with the complete Freund's adjuvant (CFA) we also observed slightly increased values of the MDA in the case of the control group (CON) and the exposed groups (EMF and TRAM/EMF). The MDA values concerning kidneys remained at the same levels in the control, exposed, and not-exposed group treated with tramadol. Results for

healthy rats and animals with inflammation did not differ significantly. CONCLUSIONS: The electromagnetic field exposure (EMF), applied in the repeated manner together with opioid drug tramadol (TRAM), slightly enhanced lipid peroxidation level in brain, blood, and kidneys.

Bodin R, Seewooruttun C, Corona A, Delanaud S, Pelletier A, Villégier A. Sex-dependent impact of perinatal 5G electromagnetic field exposure in the adolescent rat behavior. Environ Sci Pollut Res Int 30(53):113704-113717, 2023.

The fifth generation (5G) network is currently being worldwide spread out, raising questions about the potential impact of this new technology, particularly on immature organisms. The current study aimed to investigate the effects of daily 5G electromagnetic field (EMF) perinatal exposure on the neurodevelopment of rats. The exposure level was set to the limit of whole-body public exposure defined by the International Commission on Non-Ionizing Radiation Protection. The mother rat specific absorption rate (SAR) was 0.07 W/kg for 22 h/day at 3500 MHz continuous wave from gestational day (GD) 8 to post-natal day (PND) 21. Clinical observations were performed on weight, length, sex ratio, number of pups per litter, and number of stillborn in sham and EMF-exposed groups (n = 7). The age of pinna ear detachment, incisor eruption, and eye opening were recorded. Behavior was assessed on righting, gripping, and negative geotaxis reflexes at PND 3 or 7 and on stereotyped and horizontal movements in the open field at PND 43. Our results indicated that both male and female pups showed delayed incisor eruption in the EMF-exposed group compared to the sham group (+ 1 day). Regarding activity in the open field, adolescent females showed less stereotyped movements (- 70%), while adolescent males showed more stereotyped movements (+ 50%) compared to the sham-exposed adolescent rats. Thus, the present study suggested that perinatal exposure to 5G at SAR level below reglementary threshold led to perturbations in the descendants seen in juveniles and adolescents.

Bodin R, Godin L, Mougin C, Lecomte A, Larrigaldie V, Feat-Vetel J, Méresse S, Montécot-Dubourg C, Marcelo P, Mortaud S, Villegier AS. Altered development in rodent brain cells after 900MHz radiofrequency exposure. Neurotoxicology. 2025 Sep 2:103312

Health risks related to 900MHz 2G frequency exposure remain inconclusive under current regulatory standards. Research into potential long-term effects is ongoing, particularly as the use of mobile networks and wireless devices increases. This study investigates the effects of non-thermal exposure levels of mobile phone 900MHz radiofrequency electromagnetic field (RF-EMF) on rodent neurodevelopment. In vivo, the effects of pre- and post-natal 0.08 and 0.4W/kg specific absorption rate (SAR) exposure were assessed for their impact on the proteomic profile at postnatal day 0 (PND 0). Brain-derived neurotrophic factor (BDNF), BrdU+ proliferative cells, synaptogenesis, and oxidative stress in the hippocampus and cortex of rat pups were studied at PND 8 and PND 17. Effects of the lowest SAR (0.08W/kg) were assessed in vitro to afford mechanistic data regarding neural stem cells (NSCs) differentiation. In vivo results showed a decrease in BDNF level and BrdU+ proliferative cells with a decrease in synapse balance (excitatory synapses/inhibitory synapses). In vitro, at 0.08W/kg there was an increase in Ki-67+ proliferative cells, apoptosis, and double-strand DNA breaks in NSCs. A lower ratio of B1 cells (primary progenitors of NSCs) among total cerebral cells and a higher ratio of oligodendrocyte progenitor cells and astrocytes were observed in the exposed NSCs. Our findings suggest that key cellular events for brain ontogenesis are likely to undergo changes with

RF-EMF 900MHz exposure during early development. These support the hypothesis that the developing central nervous system is vulnerable to RF-EMF exposures in rodents at regulatory thresholds.

Bourdineaud, J.P., Šrut, M., Štambuk, A., Tkalec, M., Brèthes, D., Malarić, K., Klobučar, G.I.V. Electromagnetic fields at a mobile phone frequency (900 MHz) trigger the onset of general stress response along with DNA modifications in Eisenia fetida earthworms. Arh Hig Rada Toksikol. 68:142-152, 2017.

Eisenia fetida earthworms were exposed to electromagnetic field (EMF) at a mobile phone frequency (900 MHz) and at field levels ranging from 10 to 120 V m-1 for a period of two hours (corresponding to specific absorption rates ranging from 0.13 to 9.33 mW kg-1). Potential effects of longer exposure (four hours), field modulation, and a recovery period of 24 h after two hours of exposure were addressed at the field level of 23 V m-1. All exposure treatments induced significant DNA modifications as assessed by a quantitative random amplified polymorphic DNA-PCR. Even after 24 h of recovery following a two hour-exposure, the number of probe hybridisation sites displayed a significant two-fold decrease as compared to untreated control earthworms, implying a loss of hybridisation sites and a persistent genotoxic effect of EMF. Expression of genes involved in the response to general stress (HSP70 encoding the 70 kDa heat shock protein, and MEKK1 involved in signal transduction), oxidative stress (CAT, encoding catalase), and chemical and immune defence (LYS, encoding lysenin, and MYD, encoding a myeloid differentiation factor) were up-regulated after exposure to 10 and modulated 23 V m-1 field levels. Western blots showing an increased quantity of HSP70 and MTCO1 proteins confirmed this stress response. HSP70 and LYS genes were up-regulated after 24 h of recovery following a two hour-exposure, meaning that the effect of EMF exposure lasted for hours.

Bozok S, Karaagac E, Sener D, Akakin D, Tumkaya L. The effects of long-term prenatal exposure to 900, 1800, and 2100 MHz electromagnetic field radiation on myocardial tissue of rats. Toxicol Ind Health 39(1):1-9, 2023.

It is well-known that wireless communication technologies facilitate human life. However, the harmful effects of electromagnetic field (EMF) radiation on the human body should not be ignored. In the present study, we evaluated the effects of long-term, prenatal exposure to EMF radiation on the myocardium of rats at varying durations. Overall, 18 pregnant Sprague-Dawley rats were assigned into six groups (n = 3 in each group). In all groups other than the control group, three pregnant rats were exposed to EMF radiation (900, 1800 and 2100 MHz) for 6, 12 and 24 h over 20 days. After delivery, the newborn male pups were identified and six newborn male pups from each group were randomly selected**.** Then, histopathological and biochemical analysis of myocardial samples were performed. When 24-h/day prenatal exposures to 900, 1800, 2100 MHz EMF radiation were evaluated, myocardial damage was greater in the 2100 MHz EMF-24h group than the other groups. In addition, when malondialdehyde (MDA) and glutathione (GSH) levels associated with reactive oxidative species (ROS) were evaluated, the MDA level was higher in the 2100 MHz EMF-24h group compared with the other groups. The GSH level was also lower in the 2100 MHz EMF-24h group. When the 6, 12 and 24 h/day prenatal exposures to 1800 MHz EMF radiation were evaluated, myocardial damage was greater in 1800 MHz EMF-24h group than the remaining groups ($p < 0.0001$). Also, MDA level was

greater in the 1800 MHz EMF-24h group compared with the other groups while the GSH level was lower in this group. It was shown that myocardial tissue was affected more by long-term exposure to EMF radiation at high frequencies. The data raise concerns that the harmful effects of non-ionizing radiation exposure on cardiac tissue will increase with 5G technology.

Burlaka A, Tsybulin O, Sidorik E, Lukin S, Polishuk V, Tsehmistrenko S, Yakymenko I. Overproduction of free radical species in embryonal cells exposed to low intensity radiofrequency radiation. Exp Oncol. 35(3):219-225, 2013.

Aim: Long-term exposure of humans to low intensity radiofrequency electromagnetic radiation (RF-EMR) leads to a statistically significant increase in tumor incidence. Mechanisms of such the effects are unclear, but features of oxidative stress in living cells under RF-EMR exposure were previously reported. Our study aims to assess a production of initial free radical species, which lead to oxidative stress in the cell. Materials and Methods: Embryos of Japanese quails were exposed in ovo to extremely low intensity RF-EMR of GSM 900 MHz (0.25 μW/cm2) during 158-360 h discontinuously (48 c - ON, 12 c - OFF) before and in the initial stages of development. The levels of superoxide (O2·-), nitrogen oxide (NO·), thiobarbituric acid reactive substances (TBARS), 8-oxo-2'-deoxyguanosine (8-oxo-dG) and antioxidant enzymes' activities were assessed in cells/tissues of 38-h, 5- and 10-day RF-EMR exposed and unexposed embryos. Results: The exposure resulted in a significant persistent overproduction of superoxide and nitrogen oxide in embryo cells during all period of analyses. As a result, significantly increased levels of TBARS and 8-oxo-dG followed by significantly decreased levels of superoxide dismutase and catalase activities were developed in the exposed embryo cells. Conclusion: Exposure of developing quail embryos to extremely low intensity RF-EMR of GSM 900 MHz during at least one hundred and fifty-eight hours leads to a significant overproduction of free radicals/reactive oxygen species and oxidative damage of DNA in embryo cells. These oxidative changes may lead to pathologies up to oncogenic transformation of cells.

Cakir T, Keskin S, Yildizhan K, Bayir MH, Altindag F, Karaman E. Alpha-Lipoic Acid Preserves Testicular Integrity Under 2.45 GHz Electromagnetic Radiation by Restoring Redox and Inflammatory Balance. Biomedicines. 13(12):3089, 2025.

Background/Objective: Electromagnetic radiation (EMR) from wireless technologies has raised concerns about male reproductive health. We aimed to evaluate the protective role of alpha-lipoic acid (ALA), a potent antioxidant, against testicular alterations induced by 2.45 GHz EMR. **Methods:** Twenty-eight adult male rats were randomly divided into four groups: control, EMR, ALA, and ALA+EMR. Animals in the EMR and ALA+EMR groups were exposed to EMR for 2 h/day for 1 month. Testicular tissues were examined histologically, stereologically, and immunohistochemically, while serum samples were analysed biochemically. **Results:** EMR exposure caused marked structural damage, including disruption of seminiferous tubule architecture, increased collagen deposition, and expansion of tubular and interstitial volumes. These pathological changes were primarily prevented in the ALA+EMR group. Immunohistochemical analyses revealed increased IL-6 and TNF-α expression following EMR exposure, whereas ALA supplementation significantly reduced these inflammatory markers and restored AR, ZO-1, and ZO-2 expression. Biochemically, EMR reduced antioxidant enzyme activities (SOD, GSH, GPx) and elevated MDA levels, indicating oxidative stress; these

parameters were reversed by ALA treatment. **Conclusions:** Collectively, our findings demonstrate that 2.45 GHz EMR induces oxidative stress, inflammation, and testicular injury, while ALA provides significant protection. These results highlight the therapeutic potential of ALA as a protective agent against EMR-related reproductive toxicity and infertility risk.

Çakmak E., Bilgici B., Engiz B.K. et al. Effects of wireless local area network exposure on testicular morphology and VEGF levels. Sci Rep (2026). https://doi.org/10.1038/ s41598-026-37323-2

This study investigated the effects of exposure to a 2.45 GHz electromagnetic field (EMF) on rat testicular tissue, focusing on histological alterations and the potential activation of the HIF1A-VEGF pathway. Twenty-four adult male albino Wistar rats were divided into a control group (n=12) with no EMF exposure and an experimental group (n=12) exposed to 2.45 GHz microwave radiation (3 V/m, SAR 0.00208 W/kg) for one hour daily over 60 days. Following the exposure period, testicular tissues were analyzed for histopathological changes, VEGFA and HIF1A gene expression levels, and VEGFA protein concentration. In rat testicular tissue, while VEGFA gene expression ($p<0.05$) and protein levels ($p<0.001$) increased in the EMF group, no significant change was detected in HIF1A gene expression level in the EMF group compared to the control group. Histological examination revealed a significant reduction in seminiferous tubule diameter ($p<0.001$), epithelial thickness ($p<0.001$), tubule density ($p<0.001$), and Sertoli cell count ($p=0.0098$) in the EMF-exposed group. It may be concluded that EMF at 2.45 GHz increases HIF1A-independent VEGF levels, and EMF exposure may cause testicular damage by increasing VEGF gene expression levels.

Calis P, Seymen M, Soykan Y, Delen K, SiravAral B, Kaplanoglu GT, Karcaaltincaba D Does exposure of smart phones during pregnancy affect the offspring's ovarian reserve? A Rat Model Study. Fetal Pediatr Pathol 40(2):142-152, 2021.

We investigated the effect of prenatal exposure to smart phone radiation and the protective effect of omega-3 on ovarian reserve of offspring. **Methods:** 24 pregnant Wistar albino rats were divided into four groups. Group-I received neither radiofrequency (RF) radiation nor omega-3, group-II received RF, group-III received RF radiation and 300 mg omega-3 and group-IV received RF radiation and 600 mg Omega-3 till birth. At 42 days, bilateral oophorectomy was performed on all female offspring for follicle count and immunohistochemical staining (GDF9, FOXO1 and TUNEL). **Results:** Group-II had significantly lower mean number of primordial ($p = 0.006$), secondary follicles($p = 0.003$) and a higher atresia score. Group-III variables were comparable with group-I variables. Group-IV had statistically higher median number of atretic follicles than group-I ($p = 0.023$). **Conclusions:** Ovarian reserve of offspring diminished with RF exposure during pregnancy. Omega-3 supplementation during pregnancy may reduce the potential premature ovarian failure.

Cantu JC, Butterworth JW, Peralta XG, Payne JA, Echchgadda I. Analysis of global DNA methylation changes in human keratinocytes immediately following exposure to a 900 MHz radiofrequency field. Bioelectromagnetics 44(3-4):77-89, 2023.

The increasing use of nonionizing radiofrequency electromagnetic fields (RF-EMFs) in a wide range of technologies necessitates studies to further understanding of biological effects from exposures to such forms of electromagnetic fields. While previous studies have described mechanisms for cellular changes occurring following exposure to low-intensity RF-EMFs, the role of molecular epigenetics has not been thoroughly investigated. Specifically unresolved is the effect of RF-EMFs on deoxyribonucleic acid (DNA) methylation, which is a powerful epigenetic process, used by cells to regulate gene expression. DNA methylation is dynamic and can be rapidly triggered in response to external stimuli such as exposure to RF-EMFs. In the present study, we performed a global analysis of DNA methylation patterns in human keratinocytes exposed to 900 MHz RF-EMFs for 1 h at a low dose rate (estimated mean specific absorption rate (SAR) < 10 mW/kg). We used a custom system to allow stable exposure of cell cultures to RF-EMFs under biologically relevant conditions (37 °C, 5% CO_2 , 95% humidity). We performed whole genome bisulfite sequencing directly following RF-EMF exposure to examine the immediate changes in DNA methylation patterns and identify early differentially methylated genes in RF-EMF-exposed keratinocytes. By correlating global gene expression to whole genome bisulfite sequencing, we identified six common targets that were both differentially methylated and differentially expressed in response to RF-EMF exposure. The results highlight a potential epigenetic role in the cellular response to RF-EMFs. Particularly, the six identified targets may potentially be developed as epigenetic biomarkers for immediate responses to RF-EMF exposure.

Cao H, Qin F, Liu X, Wang J, Cao Y, Tong J, Zhao H. Circadian rhythmicity of antioxidant markers in rats exposed to 1.8 GHz radiofrequency fields. Int J Environ Res Public Health. 12(2):2071-2087, 2015.

BACKGROUND: The potential health risks of exposure to Radiofrequency Fields (RF) emitted by mobile phones are currently of considerable public interest, such as the adverse effects on the circadian rhythmicities of biological systems. To determine whether circadian rhythms of the plasma antioxidants (Mel, GSH-Px and SOD) are affected by RF, we performed a study on male Sprague Dawley rats exposed to the 1.8 GHz RF. METHODS: All animals were divided into seven groups. The animals in six groups were exposed to 1.8 GHz RF (201.7 μW/cm2 power density, 0.05653 W/kg specific absorption rate) at a specific period of the day (3, 7, 11, 15, 19 and 23 h GMT, respectively), for 2 h/day for 32 consecutive days. The rats in the seventh group were used as sham-exposed controls. At the end of last RF exposure, blood samples were collected from each rat every 4 h (total period of 24 h) and also at similar times from sham-exposed animals. The concentrations of three antioxidants (Mel, GSH-Px and SOD) were determined. The data in RF-exposed rats were compared with those in sham-exposed animals. RESULTS: circadian rhythms in the synthesis of Mel and antioxidant enzymes, GSH-Px and SOD, were shifted in RF-exposed rats compared to sham-exposed animals: the Mel, GSH-Px and SOD levels were significantly decreased when RF exposure was given at 23 and 3 h GMT. CONCLUSION: The overall results indicate that there may be adverse effects of RF exposure on antioxidant function, in terms of both the daily antioxidative levels, as well as the circadian rhythmicity.

Cappucci, U., Assunta Maria Casale, Mirena Proietti, Fiorenzo Marinelli, Livio Giuliani, Lucia Piacentini. Wi-Fi related radiofrequency electromagnetic fields promote transposable element dysregulation and genomic instability in *Drosophila melanogaster.* Cells 11(24):4036, 2022.

Exposure to artificial radio frequency electromagnetic fields (RF-EMFs) has greatly increased in recent years, thus promoting a growing scientific and social interest in deepening the biological impact of EMFs on living organisms. The current legislation governing the exposure to RF-EMFs is based exclusively on their thermal effects, without considering the possible non-thermal adverse health effects from long term exposure to EMFs. In this study we investigated the biological non-thermal effects of low-level indoor exposure to RF-EMFs produced by WiFi wireless technologies, using *Drosophila melanogaster* as the model system. Flies were exposed to 2.4 GHz radiofrequency in a Transverse Electromagnetic (TEM) cell device to ensure homogenous controlled fields. Signals were continuously monitored during the experiments and regulated at non thermal levels. The results of this study demonstrate that WiFi electromagnetic radiation causes extensive heterochromatin decondensation and thus a general loss of transposable elements epigenetic silencing in both germinal and neural tissues. Moreover, our findings provide evidence that WiFi related radiofrequency electromagnetic fields can induce reactive oxygen species (ROS) accumulation, genomic instability, and behavioural abnormalities. Finally, we demonstrate that WiFi radiation can synergize with RasV12 to drive tumor progression and invasion. All together, these data indicate that radiofrequency radiation emitted from WiFi devices could exert genotoxic effects in *Drosophila* and set the stage to further explore the biological effects of WiFi electromagnetic radiation on living organisms.

Capri, M., Scarcella, E., Fumelli, C., Bianchi,. S., Mesirca, P., Agostini, C., Antolini, A., Schiavoni, A., Castellani, G., Bersani, F., Franceschi, C. In vitro exposure of human lymphocytes to 900 MHz CW and GSM modulated radiofrequency: studies of proliferation, apoptosis and mitochondrial membrane potential. Radiat Res. 162:211-218, 2004.

The aim of this study was to investigate the nonthermal effects of radiofrequency (RF) fields on human immune cells exposed to a Global System for Mobile Communication (GSM) signal generated by a commercial cellular phone and by a sinusoidal non-modulated signal. To assess whether mobile phone RF-field exposure affects human immune cell functions, peripheral blood mononuclear cells (PBMCs) from healthy donors were exposed in vitro to a 900 MHz GSM or continuous-wave (CW) RF field 1 h/day for 3 days in a transverse electromagnetic mode (TEM) cell system (70-76 mW/kg average specific absorption rate, SAR). The cells were cultured for 48 or 72 h, and the following end points were studied: (1) mitogen-induced proliferation; (2) cell cycle progression; (3) spontaneous and 2-deoxy-D-ribose (dRib)-induced apoptosis; (4) mitochondrial membrane potential modifications during spontaneous and dRib-induced-apoptosis. Data obtained from cells exposed to a GSM-modulated RF field showed a slight decrease in cell proliferation when PBMCs were stimulated with the lowest mitogen concentration and a slight increase in the number of cells with altered distribution of phosphatidylserine across the membrane. On the other hand, cell cycle phases, mitochondrial membrane potential and susceptibility to apoptosis were found to be unaffected by the RF field.

When cells were exposed to a CW RF field, no significant modifications were observed in comparison with sham-exposed cells for all the end points investigated.

Čermak AMM, Ilić K, Pavičić I. Microtubular structure impairment after GSM-modulated RF radiation exposure. Arh Hig Rada Toksikol. 71:205-210, 2020.

The objective of the study was to investigate whether low-level 915 MHz GSM-modulated radiofrequency (RF) radiation impairs microtubular structure and affects normal cell growth. V79 cells were exposed to a GSM-modulated field in a Gigahertz Transversal Electromagnetic Mode cell (GTEM cell) for 1, 2, and 3 h. Signal generator combined with power and chip modulator generated the electromagnetic field (EMF). The electric field strength was adjusted to 10, 20, and 30 V/m, and the average specific absorption rate (SAR) was calculated to be 0.23, 0.8, and 1.6 W/kg. The structure of microtubule proteins was assessed by indirect immunocytochemistry, and cell growth was determined based on cell counts taken every day over six post-exposure days. Three-hour radiation exposure significantly altered microtubule structure regardless of the electric field strength. Moreover, on the third post-exposure day, three-hour radiation significantly reduced cell growth, regardless of field strength. The same was observed with two-hour exposure at 20 and 30 V/m. In conclusion, 915 MHz GSM-modulated RF radiation affects microtubular proteins in a time-dependent manner, which, in turn, affects cell proliferation. Our future research will focus on microtubule structure throughout the cell cycle and RF radiation effects on mitotic spindle.

Cetin H, Nazıroğlu M, Celik O, Yüksel M, Pastacı N, Ozkaya MO. Liver antioxidant stores protect the brain from electromagnetic radiation (900 and 1800 MHz)-induced oxidative stress in rats during pregnancy and the development of offspring. J Matern Fetal Neonatal Med. 27(18):1915-1921, 2014.

Objectives: The present study determined the effects of mobile phone (900 and 1800 MHz)-induced electromagnetic radiation (EMR) exposure on oxidative stress in the brain and liver as well as the element levels in growing rats from pregnancy to 6 weeks of age. Methods: Thirty-two rats and their offspring were equally divided into 3 different groups: the control, 900 MHz, and 1800 MHz groups. The 900 MHz and 1800 MHz groups were exposed to EMR for 60 min/day during pregnancy and neonatal development. At the 4th, 5th, and 6th weeks of the experiment, brain samples were obtained. Results: Brain and liver glutathione peroxidase (GSH-Px) activities, as well as liver vitamin A and β-carotene concentrations decreased in the EMR groups, although brain iron, vitamin A, and β-carotene concentrations increased in the EMR groups. In the 6th week, selenium concentrations in the brain decreased in the EMR groups. There were no statistically significant differences in glutathione, vitamin E, chromium, copper, magnesium, manganese, and zinc concentrations between the 3 groups. Conclusion: EMR-induced oxidative stress in the brain and liver was reduced during the development of offspring. Mobile phone-induced EMR could be considered as a cause of oxidative brain and liver injury in growing rats.

Ceyhan AM, Akkaya VB, Güleçol ŞC, Ceyhan BM, Özgüner F, Chen W. Protective effects of β-glucan against oxidative injury induced by 2.45-GHz electromagnetic radiation in the skin tissue of rats. Arch Dermatol Res. 304(7):521-527, 2012.

In recent times, there is widespread use of 2.45-GHz irradiation-emitting devices in industrial, medical, military and domestic application. The aim of the present study was to investigate the effect of 2.45-GHz electromagnetic radiation (EMR) on the oxidant and antioxidant status of skin and to examine the possible protective effects of β-glucans against the oxidative injury. Thirty-two male Wistar albino rats were randomly divided into four equal groups: control; sham exposed; EMR; and EMR + β-glucan. A 2.45-GHz EMR emitted device from the experimental exposure was applied to the EMR group and EMR + β-glucan group for 60 min daily, respectively, for 4 weeks. β-glucan was administered via gavage at a dose of 50 mg/kg/day before each exposure to radiation in the treatment group. The activities of antioxidant enzymes, superoxide dismutase (SOD), glutathione peroxidase (GSH-Px) and catalase (CAT), as well as the concentration of malondialdehyde (MDA) were measured in tissue homogenates of the skin. Exposure to 2.45-GHz EMR caused a significant increase in MDA levels and CAT activity, while the activities of SOD and GSH-Px decreased in skin tissues. Systemic β-glucan significantly reversed the elevation of MDA levels and the reduction of SOD activities. β-glucan treatment also slightly enhanced the activity of CAT and prevented the depletion of GSH-Px activity caused by EMR, but not statistically significantly. The present study demonstrated the role of oxidative mechanisms in EMR-induced skin tissue damages and that β-glucan could ameliorate oxidative skin injury via its antioxidant properties.

Chandel S, Kaur S, Issa M, Singh HP, Batish DR, Kohli RK. Exposure to mobile phone radiations at 2350 MHz incites cyto- and genotoxic effects in root meristems of *Allium cepa*. J Environ Health Sci Eng. 17(1):97-104, 2019a.

BACKGROUND: The exponential increase of electromagnetic field radiations (EMF-r) in the natural environment has raked up the controversies regarding their biological effects. Concern regarding the putative capacity of EMF-r to affect living beings has been growing due to the ongoing elevation in the use of high frequency EMF-r in communication systems, e.g. Mobile phones. METHODS: In the present study, we tried to examine the cyto- and genotoxic potential of mobile phone EMF-r at 2350 MHz using onions (*Allium cepa* L.). Fresh adventitious onion roots were exposed to continuous EMF-r at 2350 MHz for different time periods (1 h, 2 h and 4 h). The evaluation of cytotoxicity was done in terms of mitotic index (MI), phase index and chromosomal aberrations. Genotoxicity was investigated employing comet assay in terms of changes in % HDNA (head DNA) and % TDNA (tail DNA), TM (tail moment) and OTM (olive tail moment). Data were analyzed using one-way ANOVA and mean values were separated using post hoc Tukey's test. RESULTS: The results manifested a significant increase of MI and chromosomal aberrations (%) upon 4 h, and ≥ 2 h of exposure, respectively, as compared to the control. No specific changes in phase index in response to EMF-r exposure were observed. The % HDNA and % TDNA values exhibited significant changes in contrast to that of control upon 2 h and 4 h of exposure, respectively. However, TM and OTM did not change significantly. CONCLUSIONS: Our results infer that continuous exposures of radiofrequency EMF-r (2350 MHz) for long durations have a potential of inciting cyto- and genotoxic effects in onion root meristems.

Chandel S, Kaur S, Issa M, Singh HP, Batish DR, Kohli RK. Appraisal of immediate and late effects of mobile phone radiations at 2100 MHz on mitotic activity and DNA integrity in root meristems of Allium cepa. Protoplasma. 256(5):1399-1407, 2019b.

The present study evaluated the potential of 2100 MHz radiofrequency radiations to act as cytotoxic and genotoxic agent. Fresh onion (Allium cepa L.) roots were exposed to electromagnetic field radiations (EMF-r) for different durations (1 h and 4 h) and evaluated for mitotic index (MI), phase index, chromosomal aberrations, and DNA damage. DNA damage was investigated with the help of the comet assay by assessing various parameters like % head DNA (HDNA), % tail DNA (TDNA), tail moment (TM), and olive tail moment (OTM). Effects of EMF-r exposure were also compared with that of methyl methanesulfonate (MMS; 90 μM), which acted as a positive control. The post-exposure effects of EMF-r after providing the test plants with an acclimatization period of 24 h were also evaluated. Compared to the control, a significant increase in the MI and aberration percentage was recorded upon 4 h of exposure. However, no specific trend of phase index in response to exposure was detected. EMF-r exposure incited DNA damage with a significant decrease in HDNA accompanied by an increase in TDNA upon exposure of 4 h. However, TM and OTM did not change significantly upon exposure as compared to that of control. Analysis of the post-exposure effects of EMF-r did not show any significant change/recovery. Our data, thus, suggest the potential cytotoxic and genotoxic nature of 2100 MHz EMF-r. Our study bears great significance in view of the swiftly emergent EMF-r in the surrounding environment and their potential for inciting aberrations at the chromosomal level, thus posing a genetic hazard.

Chaturvedi, C.M., Singh, V.P., Singh, P., Basu, P., Singaravel, M., Shukla, R.K., Dhawan, A., Pati, A.K., Gangwar, R.K., Singh, S.P. 2.45 GHZ (CW) microwave irradiation alters circadian organization, spatial memory, DNA structure in the brain cells and blood cell counts of male mice, Mus musculus. Prog Electromagn Res B. 29:23-42, 2011.

Present study examines biological effects of 2.45 GHz microwave radiation in Parkes strain mice. Forty-day-old mice were exposed to CW (continuous wave) microwave radiation (2 h/day for 30 days). Locomotor activity was recorded on running wheel for 12 days prior to microwave exposure (pre-exposure), 7 days during the first week of exposure (short-term exposure) and another 7-day spell during the last week of the 30-day exposure period (long-term exposure). Morris water maze test was performed from 17th to 22nd day of exposure. At the termination of the exposure, blood was processed for hematological parameters, brain for comet assay, epididymis for sperm count and motility and serum for SGOT (serum glutamate oxaloacetate transaminase) and SGPT (serum glutamate pyruvate transaminase). The results show that long-term radiation-exposed group exhibited a positive ψ□(phase angle difference) for the onset of activity with reference to lights-off timing and most of the activity occurred within the light fraction of the LD (light: dark) cycle. Microwave radiation caused an increase in erythrocyte and leukocyte counts, a significant DNA strand break in brain cells and the loss of spatial memory in mice. This report for the first time provides experimental evidence that continuous exposure to low intensity microwave radiation may have an adverse effect on the brain function by altering circadian system and rate of DNA damage

Chauhan P, Verma HN, Sisodia R, Kesari KK. Microwave radiation (2.45 GHz)-induced oxidative stress: Whole-body exposure effect on histopathology of Wistar rats. Electromagn Biol Med. 36(1):20-30, 2017.

Man-made microwave and radiofrequency (RF) radiation technologies have been steadily increasing with the growing demand of electronic appliances such as microwave oven and cell phones. These appliances affect biological systems by increasing free radicals, thus leading to oxidative damage. The aim of this study was to explore the effect of 2.45 GHz microwave radiation on histology and the level of lipid peroxide (LPO) in Wistar rats. Sixty-day-old male Wistar rats with 180 ± 10 g body weight were used for this study. Animals were divided into two groups: sham exposed (control) and microwave exposed. These animals were exposed for 2 h a day for 35 d to 2.45 GHz microwave radiation (power density, 0.2 mW/cm^2). The whole-body specific absorption rate (SAR) was estimated to be 0.14 W/kg. After completion of the exposure period, rats were sacrificed, and brain, liver, kidney, testis and spleen were stored/preserved for determination of LPO and histological parameters. Significantly high level of LPO was observed in the liver ($p < 0.001$), brain ($p < 0.004$) and spleen ($p < 0.006$) in samples from rats exposed to microwave radiation. Also histological changes were observed in the brain, liver, testis, kidney and spleen after whole-body microwave exposure, compared to the control group. Based on the results obtained in this study, we conclude that exposure to microwave radiation 2 h a day for 35 d can potentially cause histopathology and oxidative changes in Wistar rats. These results indicate possible implications of such exposure on human health.

Chen L, Qin F, Chen Y, Sun J, Tong J.[Chronotoxicity of 1800 MHz microwave radiation on sex hormones and spermatogenesis in male mice]. Wei Sheng Yan Jiu. 43(1):110-115, 2014. [Article in Chinese]

OBJECTIVE: To study the chronotoxicity of 1800 MHz microwave radiation on the male reproductive system. METHODS: Sixty healthy male C57 mice with circadian rhythm in a 12:12 h light-dark photoperiod were divided into false radiation group (Sham) and microwave radiation (MR) group exposed to 1800 MHz RF at 208 microW/cm2 power (SAR: 0 .2221 W/kg) density at different zeitgeber times of a day (ZT01:00, ZT05:00, ZT09 : 00, ZT13: 00, ZT17 : 00, ZT21 : 00) for continuous 32 days with 2 h/d. The testicular sperm head was counted with a microscope, and serum testosterone (T) and estradiol (E2) levels were measured by ELISA method. RESULTS: Compared with the sham group,microwave radiation induced reduced level in testicular sperm head count and serum testosterone, while the level of serum estradiol increased. Also, the circadian rhythms of testicular sperm head count and estradiol disappeared after the microwave radiation. CONCLUSION: 1800 MH2 microwave radiation may disturb the level as well as circadian rhythmicity of the reproductive functions in male mice.

Comelekoglu, U., Aktas, S., Demirbag, B., Karagul, M.I., Yalin, S., Yildirim, M., Akar, A., Engiz, B.K., Sogut, F., Ozbay, E. Effect of low-level 1800 MHz radiofrequency radiation on the rat sciatic nerve and the protective role of paricalcitol. Bioelectromagnetics. 39:631-643, 2018.

The nervous system is an important target of radiofrequency (RF) radiation exposure since it is the excitable component that is potentially able to interact with electromagnetic fields. The present study was designed to investigate the effects of 1,800 MHz RF radiation and the

protective role of paricalcitol on the rat sciatic nerve. Rats were divided into four groups as control, paricalcitol, RF, and RF + paricalcitol. In RF groups, the rats were exposed to 1,800 MHz RF for 1 h per day for 4 weeks. Control and paricalcitol rats were kept under the same conditions without RF application. In paricalcitol groups, the rats were given 0.2 μg/kg/day paricalcitol, three times per week for 4 weeks. Amplitude and latency of nerve compound action potentials, catalase activities, malondialdehyde (MDA) levels, and ultrastructural changes of sciatic nerve were evaluated. In the RF group, a significant reduction in amplitude, prolongation in latency, an increase in the MDA level, and an increase in catalase activity and degeneration in the myelinated nerve fibers were observed. The electrophysiological and histological findings were consistent with neuropathy, and the neuropathic changes were partially ameliorated with paricalcitol administration.

Coskun ZO, Tumkaya L, Yilmaz A, Dursun E, Mercantepe T, Kalkan Y, Ersoz S. Does Radiofrequency Radiation From Mobile Phones Affect the Formation of Parotid Gland Malignancy? An Experimental Study. Ear Nose Throat J 2024 Sep 27:1455613241287295. doi: 10.1177/01455613241287295. Online ahead of print.

Objectives: The use of mobile phone is increasing around the world. Although it is beneficial in terms of communication, the electromagnetic radiations emitted by mobile phones may cause undesirable biological effects on the human body. In practical use, the tissue with which mobile phones come into most and are closest is the parotid gland. This study investigated the effects of the 1800 MHz electromagnetic field created by a generator on the parotid gland in rats. **Methods:** A total of 21 Sprague-Dawley Albino rats were included in the study. The rats were randomly divided into three equal groups. To simulate a mobile phone in conversation mode, the first study group was exposed to an 1800-MHz electromagnetic field for 6 hours a day for 30 days, and the second study group was exposed to an 1800-MHz electromagnetic field for 12 hours a day for 30 days. After 30 days, rats were sacrificed, and histopathological and immunohistochemical methods were used to evaluate the effects on the parotid gland. The total antioxidant level and the total oxidant level were measured biochemically in homogenized parotid tissue. **Results:** Histopathological results showed an increase in degeneration in rats exposed to electromagnetic fields for 6 and 12 hours a day, and immunohistochemical analysis showed an increase in the apoptotic index in both study groups ($P = .001$, $P < .001$). Intranuclear inclusions was observed during histopathological examination performed by electron microscopy. **Conclusions:** This study observed that the 1800 MHz electromagnetic field caused undesirable adverse histopathological and biochemical effects on the parotid gland of rats. Histopathological and biochemical findings were detected with increasing contact and exposure time. This study will lead to other studies on this topic and contribute to the literature by completing other studies.

D'Andrea JA, DeWitt JR, Gandhi OP, Stensaas S, Lords JL, Nielson NC. Behavioral and physiological effects of chronic 2,450-MHz microwave irradiation of the rat at 0.5 mW/cm^2. Bioelectromagnetics 7(1):45-56, 1986.

Adult male Long-Evans rats were intermittently exposed to 2450 MHz CW microwaves at an average power density of 0.5 mW/cm^2 for 90 days. The resulting SAR was 0.14 W/kg (range

0.11 to 0.18 W/kg). The animals were exposed 7 h/day, 7 days/wk, for a total of 630 h in a monopole-above-ground radiation chamber while housed in Plexiglas holding cages. Daily measures of body mass and food and water intake indicated no statistically significant effects of microwave exposure. Monthly assessment of reactivity to electric footshock, levels of cholinesterase and sulfhydryl groups in blood, and 17-ketosteroids in urine revealed no reliable differences between 14 sham-exposed and 14 microwave-exposed rats. After the 90 days of exposure, seven rats, randomly chosen from each group, were assessed for open-field behavior, shuttlebox performance, and schedule-controlled (IRT schedule) lever pressing for food pellets. Statistically significant differences between microwave-exposed and sham-exposed rats were observed in shuttlebox performances and lever pressing. Post mortem measures of mass of several organs and microscopic examination of adrenal tissue revealed no differences between the two groups of animals.

Dasdag S, Taş M, Akdag MZ, Yegin K. Effect of long-term exposure of 2.4 GHz radiofrequency radiation emitted from Wi-Fi equipment on testes functions. Electromagn Biol Med. 34(1):37-42, 2015.

The aim of this study was to investigate long-term effects of radiofrequency radiation (RFR) emitted from a Wireless Fidelity (Wi-Fi) system on testes. The study was carried out on 16 Wistar Albino adult male rats by dividing them into two groups such as sham (n: 8) and exposure (n: 8). Rats in the exposure group were exposed to 2.4 GHz RFR radiation for 24 h/d during 12 months (1 year). The same procedure was applied to the rats in the sham control group except the Wi-Fi system was turned off. Immediately after the last exposure, rats were sacrificed and reproductive organs were removed. Motility (%), concentration ($\times 10^6$/mL), tail defects (%), head defects (%) and total morphologic defects (%) of sperms and weight of testes (g), left epididymis (g), prostate (g), seminal vesicles (g) were determined. Seminiferous tubules diameter (μm) and tunica albuginea thickness (μm) were also measured. However, the results were evaluated by using Johnsen's score. Head defects increased in the exposure group ($p < 0.05$) while weight of the epididymis and seminal vesicles, seminiferous tubules diameter and tunica albuginea thickness were decreased in the exposure group ($p < 0.01$, $p < 0.001$, $p < 0.0001$). However, other alterations of other parameters were not found significant ($p > 0.05$). In conclusion, we observed that long-term exposure of 2.4 GHz RF emitted from Wi-Fi (2420 μW/kg, 1 g average) affects some of the reproductive parameters of male rats. We suggest Wi-Fi users to avoid long-term exposure of RF emissions from Wi-Fi equipment.

Delavarifar S, Razi Z, Tamadon A, Rahmanifar F, Mehrabani D, Owjfard M, Koohi-Hoseinabadi O, Zaker Abasali S. Low-power density radiations eeeemitted from common Wi-Fi routers influence sperm concentration and sperm histomorphometric parameters: A new horizon on male infertility treatment. J Biomed Phys Eng 10(2):167-176, 2020.

Background: Male infertility is defined as an inability to impregnate a fertile female; it is a widespread problem which is usually caused by some male factors such as low quantity and quality of sperm, specifically oligospermia and azoospermia. **Objective:** This study aimed to evaluate the bio-positive effects of low power density Wi-Fi radiation on the reproductive system of infertile and healthy mice. **Materials and methods:** In this experimental study, thirty adult

male Balb/c mice were randomly divided into 5 groups. Groups oligospermic-sham (OS), oligospermic-exposure 1 (OE1) and oligospermic-exposure 2 (OE2) received Busulfan, 10 mg/kg, intraperitoneally, but the control-sham (CS) and control-exposure (CE) groups left without Busulfan therapy. Groups CE, OE1 and OE2 were exposed to 2.4 GHz Wi-Fi radiation while, the CS and OS were sham exposed to Wi-Fi radiation without energizing the Wi-Fi router. The right and left testes and right epididymis were dissected out and histopathological, histomorphologic changes and the quality of the sperms were analyzed. **Results:** Low power density Wi-Fi radiation significantly increased sperm concentration in the CE group compared to that in CS, while enhancement of spermatid cells was not significant. Sperm concentration in OE2 was more than that in OE1 as the spermatid cells enhanced. **Conclusion:** Findings revealed that radiation hormesis induced by low power density Wi-Fi radiation have biological beneficial effects on mouse sperm concentration and sperm histomorphometric parameters.

Demirbağ B, Aktaş S, Çömelekoğlu Ü, Kara I, Yildirim M, Derici Yildirim DD. Protective effect of paricalcitol in rat testicular damage induced by subchronic 1800 MHz radiofrequency radiation. Biochem Biophys Res Commun 680:42-50, 2023.

In the present study, the possible protective effects of paricalcitol (P) were investigated in testicular damage because of 1800 MHz radiofrequency radiation (RFR) exposure. Male Sprague Dawley rats 8-10 weeks old (n = 28) were randomly divided into four groups as control (C) (n = 7), RFR (n = 7, 1800 MHz RFR 1 h/day for 30 days), P (n = 7, 0.2 μg/kg paricalcitol, 3 times a week for 30 days), and RFR + P (n = 7, 1800 MHz RFR 1 h/day for 30 days +0.2 μg/kg paricalcitol, 3 times a week for 30 days). Testicular tissue was evaluated with histological and biochemical methods. No statistically significant differences were detected between the groups in seminiferous tubule diameters and germinal epithelial thicknesses. While ultrastructural changes were observed in the seminiferous tubule and Leydig cells in the RFR group, these changes were decreased in the RFR + P group. It was found that the Johnsen Score, Ki67, and p63 immunoreactivity scores (IRS), superoxide dismutase (SOD), and catalase (CAT) activities in the RFR + P group were statistically increased as compared to the RFR group and the malondialdehyde (MDA) levels were decreased statistically and significantly. These results show that paricalcitol administration may have an ameliorative effect on testicular damage occurring because of 1800 MHz RFR exposure.

de Pomerai, D.I., Smith, B., Dawe, A., North, K., Smith, T., Archer, D.B., Duce, I.R., Jones, D., Candido, E.P. Microwave radiation can alter protein conformation without bulk heating. FEBS Lett. 543:93-97, 2003.

Exposure to microwave radiation enhances the aggregation of bovine serum albumin in vitro in a time- and temperature-dependent manner. Microwave radiation also promotes amyloid fibril formation by bovine insulin at 60 degrees C. These alterations in protein conformation are not accompanied by measurable temperature changes, consistent with estimates from field modelling of the specific absorbed radiation (15-20 mW kg(-1)). Limited denaturation of cellular proteins could explain our previous observation that modest heat-shock responses are induced by microwave exposure in Caenorhabditis elegans. We also show that heat-shock responses both to heat and microwaves are suppressed after RNA interference ablating heat-shock factor function.

Deshmukh, P.S., Megha, K., Banerjee, B.D., Ahmed, R.S., Chandn, S., Abegaonkar, M.P., Tripath, A.K. Detection of low level microwave radiation induced deoxyribonucleic acid damage vis-à-vis genotoxicity in brain of Fischer rats. Toxicol Int. 20:19-24, 2013a.

Background: Non-ionizing radiofrequency radiation has been increasingly used in industry, commerce, medicine and especially in mobile phone technology and has become a matter of serious concern in present time. **Objective:** The present study was designed to investigate the possible deoxyribonucleic acid (DNA) damaging effects of low-level microwave radiation in brain of Fischer rats. **Materials and methods:** Experiments were performed on male Fischer rats exposed to microwave radiation for 30 days at three different frequencies: 900, 1800 and 2450 MHz. Animals were divided into 4 groups: Group I (Sham exposed): Animals not exposed to microwave radiation but kept under same conditions as that of other groups, Group II: Animals exposed to microwave radiation at frequency 900 MHz at specific absorption rate (SAR) 5.953 × 10(-4) W/kg, Group III: Animals exposed to 1800 MHz at SAR 5.835 × 10(-4) W/kg and Group IV: Animals exposed to 2450 MHz at SAR 6.672 × 10(-4) W/kg. At the end of the exposure period animals were sacrificed immediately and DNA damage in brain tissue was assessed using alkaline comet assay. **Results:** In the present study, we demonstrated DNA damaging effects of low level microwave radiation in brain. **Conclusion:** We concluded that low SAR microwave radiation exposure at these frequencies may induce DNA strand breaks in brain tissue.

Deshmukh PS, Banerjee BD, Abegaonkar MP, Megha K, Ahmed RS, Tripathi AK, Mediratta PK. Effect of low level microwave radiation exposure on cognitive function and oxidative stress in rats. Indian J Biochem Biophys. 50(2):114-119, 2013b.

Use of wireless communicating devices is increasing at an exponential rate in present time and is raising serious concerns about possible adverse effects of microwave (MW) radiation emitted from these devices on human health. The present study aimed to evaluate the effects of 900 MHz MW radiation exposure on cognitive function and oxidative stress in blood of Fischer rats. Animals were divided into two groups (6 animals/group): Group I (MW-exposed) and Group II (Sham-exposed). Animals were subjected to MW exposure (Frequency 900 MHz; specific absorption rate 8.4738 x 10(-5) W/kg) in Gigahertz transverse electromagnetic cell (GTEM) for 30 days (2 h/day, 5 days/week). Subsequently, cognitive function and oxidative stress parameters were examined for each group. Results showed significant impairment in cognitive function and increase in oxidative stress, as evidenced by the increase in levels of MDA (a marker of lipid peroxidation) and protein carbonyl (a marker of protein oxidation) and unaltered GSH content in blood. Thus, the study demonstrated that low level MW radiation had significant effect on cognitive function and was also capable of leading to oxidative stress.

Deshmukh, P.S., Nasare, N., Megha, K., Banerjee, B.D., Ahmed, R.S., Singh, D., Abegaonkar, M.P., Tripathi, A.K., Mediratta, P.K. Cognitive impairment and neurogenotoxic effects in rats exposed to low-Intensity microwave radiation. Int J Toxicol. 34:284-290, 2015.

The health hazard of microwave radiation (MWR) has become a recent subject of interest as a result of the enormous increase in mobile phone usage. The present study aimed to investigate the effects of chronic low-intensity microwave exposure on cognitive function, heat shock

protein 70 (HSP70), and DNA damage in rat brain. Experiments were performed on male Fischer rats exposed to MWR for 180 days at 3 different frequencies, namely, 900, 1800 MHz, and 2450 MHz. Animals were divided into 4 groups: group I: sham exposed; group II: exposed to MWR at 900 MHz, specific absorption rate (SAR) 5.953 × 10(-4) W/kg; group III: exposed to 1800 MHz, SAR 5.835 × 10(-4) W/kg; and group IV: exposed to 2450 MHz, SAR 6.672 × 10(-4) W/kg. All the rats were tested for cognitive function at the end of the exposure period and were subsequently sacrificed to collect brain. Level of HSP70 was estimated by enzyme-linked immunotarget assay and DNA damage was assessed using alkaline comet assay in all the groups. The results showed declined cognitive function, elevated HSP70 level, and DNA damage in the brain of microwave-exposed animals. The results indicated that, chronic low-intensity microwave exposure in the frequency range of 900 to 2450 MHz may cause hazardous effects on the brain.

Deshmukh, P.S., Megha, K., Nasare, N., Banerjee, B.D., Ahmed, R.S., Abegaonkar, M.P., Tripathi, A.K., Mediratta, P.K. Effect of low level subchronic microwave radiation on rat brain. Biomed Environ Sci. 29:858-867, 2016.

Objective: The present study was designed to investigate the effects of subchronic low level microwave radiation (MWR) on cognitive function, heat shock protein 70 (HSP70) level and DNA damage in brain of Fischer rats. **Methods:** Experiments were performed on male Fischer rats exposed to microwave radiation for 90 days at three different frequencies: 900, 1800, and 2450 MHz. Animals were divided into 4 groups: Group I: Sham exposed, Group II: animals exposed to microwave radiation at 900 MHz and specific absorption rate (SAR) 5.953 × 10-4 W/kg, Group III: animals exposed to 1800 MHz at SAR 5.835 × 10-4 W/kg and Group IV: animals exposed to 2450 MHz at SAR 6.672 × 10-4 W/kg. All the animals were tested for cognitive function using elevated plus maze and Morris water maze at the end of the exposure period and subsequently sacrificed to collect brain tissues. HSP70 levels were estimated by ELISA and DNA damage was assessed using alkaline comet assay. **Results:** Microwave exposure at 900-2450 MHz with SAR values as mentioned above lead to decline in cognitive function, increase in HSP70 level and DNA damage in brain. **Conclusion:** The results of the present study suggest that low level microwave exposure at frequencies 900, 1800, and 2450 MHz may lead to hazardous effects on brain.

D'Inzeo, G., Bernardi, P., Eusebi, F., Grassi, F., Tamburello, C., Zani, B.M. Microwave effects on acetylcholine-induced channels in cultured chick myotubes. Bioelectromagnetics. 9: 363-372, 1988.

The behavior of cultured myotubes from chick embryos exposed to microwaves has been experimentally analyzed. Recordings of acetylcholine-induced currents have been obtained via patch-clamp techniques using both cell-attached (single-channel current recording) and whole-cell (total current recording) configurations. During the exposure to low-power microwaves the frequency of the ACh-activated single channel openings decreased, while the ACh-induced total current showed a faster falling phase. Channel open time and conductance were not affected by microwave irradiation. It is concluded that the exposure to microwaves increases the rate of desensitization and decreases the channel opening probability. The nonthermal origin and the

molecular interaction mechanisms governing these electromagnetic-induced effects are discussed.

Djordjevic B, Sokolovic D, Kocic G, Veljkovic A, Despotovic M, Basic J, Jevtovic-Stoimenov T, Sokolovic DM. The effect of melatonin on the liver of rats exposed to microwave radiation. Bratisl Lek Listy. 116(2):96-100, 2015.

OBJECTIVES: We aimed to clarify if melatonin treatment (2 mg/kg i.p.) may favorably impact the liver tissue in rats exposed to microwave radiation. The experiment was performed on 84 six-weeks-old Wistar male rats exposed for 4h a day, for 20, 40 and 60 days, respectively, to microwaves (900 MHz, 100-300 microT, 54-160 V/m). Rats were divided in to four groups: I (control) - rats treated with saline, II (Mel) - rats treated with melatonin, III (MWs) - microwave exposed rats, IV (MWs + Mel) - MWs exposed rats treated with melatonin. We evaluated oxidative stress parameters (malondialdehyde and carbonyl group content), catalase, xanthine oxidase, deoxyribonuclease I and II activity. BACKGROUND: Oxidative stress is the key mechanism of the microwave induced tissue injury. Melatonin, a lipophilic indoleamine primarily synthesized and released from the pineal gland is a powerful antioxidant. RESULTS: Exposure to microwaves caused an increase in malondialdehyde after 40 ($p < 0.01$), protein carbonyl content after 20 ($p < 0.05$), catalase ($p < 0.05$) and xantine oxidase activity ($p < 0.05$) after 40 days. Increase in deoxyribonuclease I activity was observed after 60 days ($p < 0.05$), while deoxyribonuclease II activity was unaffected. Melatonin treatment led to malondialdehyde decrease after 40 days ($p< 0.05$), but surprisingly had no effect on other analyzed parameters. CONCLUSION: Melatonin exerts certain antioxidant effects in the liver of rats exposed to microwaves, by diminishing the intensity of lipid peroxidation(Fig. 6, Ref. 32).

Durdik M, Kosik P, Markova E, Somsedikova A, Gajdosechova B, Nikitina E, Horvathova E, Kozics K, Davis D, Belyaev I. Microwaves from mobile phone induce reactive oxygen species but not DNA damage, preleukemic fusion genes and apoptosis in hematopoietic stem/progenitor cells. Sci Rep. 9(1):16182, 2019.

Exposure to electromagnetic fields (EMF) has been associated with the increased risk of childhood leukemia, which arises from mutations induced within hematopoietic stem cells often through preleukemic fusion genes (PFG). In this study we investigated whether exposure to microwaves (MW) emitted by mobile phones could induce various biochemical markers of cellular damage including reactive oxygen species (ROS), DNA single and double strand breaks, PFG, and apoptosis in umbilical cord blood (UCB) cells including CD34+ hematopoietic stem/progenitor cells. UCB cells were exposed to MW pulsed signals from GSM900/UMTS test-mobile phone and ROS, apoptosis, DNA damage, and PFG were analyzed using flow cytometry, automated fluorescent microscopy, imaging flow cytometry, comet assay, and RT-qPCR. In general, no persisting difference in DNA damage, PFG and apoptosis between exposed and sham-exposed samples was detected. However, we found increased ROS level after 1 h of UMTS exposure that was not evident 3 h post-exposure. We also found that the level of ROS rise with the higher degree of cellular differentiation. Our data show that UCB cells exposed to pulsed MW developed transient increase in ROS that did not result in sustained DNA damage and apoptosis.

Dutta, S.K., Subramoniam, A., Ghosh, B., Parshad, R. Microwave radiation-induced calcium ion efflux from human neuroblastoma cells in culture. Bioelectromagnetics. 5:71-78, 1984.

Monolayer cultures of human neuroblastoma cells were exposed to 915-MHz radiation, with or without sinusoidal amplitude modulation (80%) at 16 Hz, at specific absorption rates (SAR) for the culture medium and cells of 0.00, 0.01, 0.05, 0.075, 0.1, 0.5, 0.75, 1.0, 1.5, 2, or 5 mW/g. A significant increase in the efflux of calcium ions (45Ca2+) as compared to unexposed control cultures occurred at two SAR values: 0.05 and 1 mW/g. Increased efflux at 0.05 mW/g was dependent on the presence of amplitude modulation at 16 Hz but at the higher value it was not. These results indicate that human neuroblastoma cells are sensitive to extremely low levels of microwave radiation at certain narrow ranges of SAR.

Dutta S.K., Ghosh, B., Blackman, C.F. Radiofrequency radiation-induced calcium ion efflux enhancement from human and other neuroblastoma cells in culture. Bioelectromagnetics. 10:197-202, 1989.

To test the generality of radiofrequency radiation-induced changes in 45Ca2+ efflux from avian and feline brain tissues, human neuroblastoma cells were exposed to electromagnetic radiation at 147 MHz, amplitude-modulated (AM) at 16 Hz, at specific absorption rates (SAR) of 0.1, 0.05, 0.01, 0.005, 0.001, and 0.0005 W/kg. Significant 45Ca2+ efflux was obtained at SAR values of 0.05 and 0.005 W/kg. Enhanced efflux at 0.05 W/kg peaked at the 13-16 Hz and at the 57.5-60 Hz modulation ranges. A Chinese hamster-mouse hybrid neuroblastoma was also shown to exhibit enhanced radiation-induced 45Ca2+ efflux at an SAR of 0.05 W/kg, using 147 MHz, AM at 16 Hz. These results confirm that amplitude-modulated radiofrequency radiation can induce responses in cells of nervous tissue origin from widely different animal species, including humans. The results are also consistent with the reports of similar findings in avian and feline brain tissues and indicate the general nature of the phenomenon.

Dutta SK, Verma M, Blackman CF, Frequency-dependent alterations in enolase activity in Escherichia coli caused by exposure to electric and magnetic fields. Bioelectromagnetics. 15:377-383, 1994.

Some neurochemical effects of low-intensity electric and magnetic fields have been shown to be nonlinear functions of exposure parameters. These effects occurred within narrow ranges of frequency and intensity. Previous studies on membrane-associated endpoints in cell culture preparations demonstrated changes in calcium efflux and in acetylcholinesterase activity following exposure to radiofrequency radiation, amplitude modulated (AM) at 16 and at 60 Hz, at a specific absorption rate of 0.05 W/kg. In this study, these modulation frequencies were tested for their influence on the activity of a cytoplasmic enzyme, enolase, which is being tested clinically for detection of neoplasia. Escherichia coli cultures containing a plasmid with a mammalian gene for enolase were exposed for 30 min, and cell extracts were assayed for enolase activity by measuring absorbance at 240 nm. The enolase activity in exposed cultures was compared to the activity in paired control cultures. Exposure to 147 MHz carrier waves at 0.05 W/kg, AM at 16 Hz showed enolase activity enhanced by 62%, and AM at 60 Hz showed enolase activity reduced by 28%. Similarly, exposure to 16 Hz fields alone, at 21.2 V/mrms

(electric) and 97 nTrms (magnetic), showed enhancement in enolase activity by 59%, whereas exposure to 60 Hz fields alone, at 14.1 V/mrms (electric) and 65 nTrms (magnetic), showed reduction in activity by 24%. Sham exposures as well as exposure to continuous-wave 147 MHz radiation at 0.05 W/kg showed no change in enolase activit

Eberhardt , J.L., Persson, B.R., Brun, A.E., Salford, L.G., Malmgren, L.O. Blood-brain barrier permeability and nerve cell damage in rat brain 14 and 28 days after exposure to microwaves from GSM mobile phones. Electromagn Biol Med. 27:215-229, 2008.

We investigated the effects of global system for mobile communication (GSM) microwave exposure on the permeability of the blood-brain barrier and signs of neuronal damage in rats using a real GSM programmable mobile phone in the 900 MHz band. Ninety-six non-anaesthetized rats were either exposed to microwaves or sham exposed in TEM-cells for 2 h at specific absorption rates of average whole-body Specific Absorption Rates (SAR) of 0.12, 1.2, 12, or 120 mW/kg. The rats were sacrificed after a recovery time of either 14 or 28 d, following exposure and the extravazation of albumin, its uptake into neurons, and occurrence of damaged neurons was assessed. Albumin extravazation and also its uptake into neurons was seen to be enhanced after 14 d (Kruskal Wallis test: $p = 0.02$ and 0.002, respectively), but not after a 28 d recovery period. The occurrence of dark neurons in the rat brains, on the other hand, was enhanced later, after 28 d ($p = 0.02$). Furthermore, in the 28-d brain samples, neuronal albumin uptake was significantly correlated to occurrence of damaged neurons (Spearman $r = 0.41$; $p < 0.01$).

Echchgadda, I., Cantu, J.C., Tolstykh, G.P., Butterworth, J.W., Payne, J.A., Ibey, B.L. Changes in the excitability of primary hippocampal neurons following exposure to 3.0 GHz radiofrequency electromagnetic fields. Sci Rep. 12:3506, 2022.

Exposures to radiofrequency electromagnetic fields (RF-EMFs, 100 kHz to 6 GHz) have been associated with both positive and negative effects on cognitive behavior. To elucidate the mechanism of RF-EMF interaction, a few studies have examined its impact on neuronal activity and synaptic plasticity. However, there is still a need for additional basic research that further our understanding of the underlying mechanisms of RF-EMFs on the neuronal system. The present study investigated changes in neuronal activity and synaptic transmission following a 60-min exposure to 3.0 GHz RF-EMF at a low dose (specific absorption rate (SAR) < 1 W/kg). We showed that RF-EMF exposure decreased the amplitude of action potential (AP), depolarized neuronal resting membrane potential (MP), and increased neuronal excitability and synaptic transmission in cultured primary hippocampal neurons (PHNs). The results show that RF-EMF exposure can alter neuronal activity and highlight that more investigations should be performed to fully explore the RF-EMF effects and mechanisms.

Eker, E.D,, Arslan, B., Yildirim, M., Akar, A., Aras, N. The effect of exposure to 1800 MHz radiofrequency radiation on epidermal growth factor, caspase-3, Hsp27 and p38MAPK gene expressions in the rat eye. Bratisl Lek Listy. 119:588-592, 2018.

Objective: Radiofrequency electromagnetic fields (RF-EMF) may induce DNA damage and oxidative stress in human lens epithelial cells (LECs). We aimed to investigate the expression levels of heat shock protein 27 (Hsp27), p38 mitogen-activated protein kinase (p38MAPK),

epidermal growth factor receptor (EGFR) and caspase-3 gene expression levels in rat eye that was exposed to 1800 MHz RF-EMF. **Methods:** Thirty-seven female Wistar albino rats were divided into three groups. The rats in the study group (n = 9) were exposed to 1800 MHz RF-EMF at an electric field 6.8 ± 0.1 V/m and 0.06 W/kg specific absorption rate (SAR) for 2 hours per day for eight weeks. Sham group (n = 9) was kept under similar conditions as the exposed group without exposure to RF-EMF. The rats in all three groups were sacrificed and their eyes were removed. Hsp27, p38MAPK, EGFR, caspase-3 gene expression levels were investigated in detail with real-time polymerase chain reactions (Real-Time PCR). **Results:** caspase-3 and p38MAPK gene expression were significantly upregulated in the ocular tissues following exposure to RF-EMF ($p < 0.05$). **Conclusion:** According to our findings, eye cells recognize EMF as a stress factor, and in response, activate caspase-3 and p38MAPK gene expressions. These results confirm that RF-EMF can cause cellular damage in rat ocular cells (Tab. 2, Fig. 3, Ref. 37).

Elekes, E, Thuroczy, G, Szabo, LD, Effect on the immune system of mice exposed chronically to 50 Hz amplitude-modulated 2.45 GHz microwaves. *Bioelectromagnetics* 17(3):246-248, 1996.

The effect of continuous (CW; 2.45 GHz carrier frequency) or amplitude-modulated (AM; 50 Hz square wave) microwave radiation on the immune response was tested. CW exposures (6 days, 3 h/day) induced elevations of the number of antibody-producing cells in the spleen of male Balb/c mice (+37%). AM microwave exposure induced elevation of the spleen index (+15%) and antibody-producing cell number (+55%) in the spleen of male mice. No changes were observed in female mice. It is concluded that both types of exposure conditions induced moderate elevation of antibody production only in male mice.

Emre M, Karamazi Y, Emre T, Varan NE, Toyran T, Yücebilgiç G. Effect of high-frequency radiofrequency (6 GHz) electromagnetic radiation on oxidative stress and kidney morphology. Toxicol Ind Health. 2026 Feb 17:7482337261422845.

This study aimed to investigate the effects of high-frequency (6 GHz) radiofrequency electromagnetic radiation (RF-EMR) exposure on oxidative stress markers and kidney morphology. Our study was designed with 3 groups, each containing 10 animals. These groups were: control, sham, and RF-EMR exposed group. No treatment was applied to the control group; the sham group was housed in the same room under the same conditions and for equal periods of time, except that the generator was turned off. The RF-EMR exposed group was exposed to 6 GHz RF-EMR emitted from the signal generator for 4 hours per day for 6 weeks. At the end of the experimental period, intracardiac blood was collected from animals and plasma oxidant (MDA), antioxidant (SOD, CAT and GSH) and cortisol markers were analyzed. After, the rats in all groups were sacrificed and kidney tissues were removed. Hematoxylin and eosin staining methods were applied histopathologically. Blood-plasma GSH, CAT, SOD and MDA levels (excluding cortisol) were lower in the RF-EMR exposed group compared to the control and sham groups ($p < .001$). No significant difference was observed in plasma levels GSH, CAT, SOD, MDA and cortisol activities between control and sham groups. In addition, we reported that the histological characteristics of kidney tissue were affected by RF-EMR. The results of our

study indicated that 6 GHz RF-EMR can function as an environmental stress factor and can modulate oxidative stress in blood plasma and cause morphological changes in kidney tissue.

Er H, Tas GG, Soygur B, Ozen S, Sati L. Acute and chronic exposure to 900 MHz radio frequency radiation activates p38/JNK-mediated MAPK pathway in rat testis. Reprod Sci 29(5):1471-1485, 2022.

The use of electronic devices such as mobile phones has had a long stretch of rapid growth all over the world. Therefore, exposure to radio frequency radiation (RFR) has increased enormously. Here, we aimed to assess the balance between cell death and proliferation and also investigate the involvement of the JNK/p38 MAPK signaling pathway in the testis of rats exposed to 900 MHz RFR in acute and chronic periods (2 h/day, 5 days/week) for 1 or 10 weeks, respectively. The expression of proliferating cell nuclear antigen (PCNA), Bcl-xL, cleaved caspase-3, phosphorylated-JNK (p-JNK), and phosphorylated-p38 (p-p38) was analyzed in line with histopathology and TUNEL analysis in rat testis. There were no histopathological differences between sham and RFR groups in the acute and chronic groups. PCNA expression was not altered between groups in both periods. However, alterations for cleaved caspase-3 and Bcl-xL were observed depending on the exposure period. TUNEL analysis showed a significant increase in the RFR group in the acute period, whereas no difference in the chronic groups for the apoptotic index was reported. In addition, both p-p38 and p-JNK protein expressions increased significantly in RFR groups in both periods. Our study indicated that 900 MHz RFR might result in alterations during acute period exposure for several parameters, but this can be ameliorated in the chronic period in rat testis. Here, we also report the involvement of the p38/JNK-mediated MAPK pathway after exposure to 900 MHz RFR. Hence, this information might shed light in future studies toward detailed molecular mechanisms in male reproduction and infertility.

Er H, Basaranlar G., Derin N., Kantar D, Ozen S. The effects of short-term and long-term 2100 MHz radiofrequency radiation on adult rat auditory brainstem response. *Open Chemistry*, *23*(1), 20250173, 2025.

Although mobile phones that work with RFR provide very important benefits for our lives, they may have negative effects. Namely, side effects, such as headaches, sleep disorders, dizziness, lower sperm quality, changes in brain potentials, an increase in oxidative stress levels, and a decrease in antioxidant parameters, have been reported due to mobile phone use. Accordingly, the aim of this research is to investigate the effects of acute and chronic 2100 MHz radiofrequency radiation (RFR) exposure on the auditory brainstem response (ABR) in adult rats. Study groups (n = 10 rats): Sh-1: sham for 1 week; Sh-10: sham for 10 weeks; 2100-1: 2100 MHz for 1 week; and 2100-10: 2100 MHz for 10 weeks. RFR groups were applied for 2 h/day (5 day/week) 2100 MHz RFR, whereas sham groups were kept under identical circumstances without RFR. ABR were recorded, and biochemical and ultrastructural examinations in the rat brain were carried out. In the acute RFR group, the latencies of all ABR waves were prolonged compared to the sham group. In the acute RFR group, brain 4-hydroxynonenal, thiobarbituric acid reactive substances, and protein carbonyl content levels increased and catalase and superoxide dismutase activities decreased compared to the acute sham

group. Edema in acute RFR group neurons, astrocytes, astrocytic end-feet, and mitochondrial damage in astrocytes were observed. Our data imply that acute exposure to 2100 MHz RFR may have adverse impacts on the auditory system, while chronic exposure with certain rest days has no harmful effects.

Er H, Hidisoglu E, Kantar D, Acun AD, Akkoyunlu G, Ozen S, Yargicoglu P. The effects of acute and chronic exposure of 2100 MHz radiofrequency radiation on rat mismatch negativity, Journal of Radiation Research and Applied Sciences. 19(1), 2026. doi:10.1016/j.jrras.2025.102126.

Cell phones operate by emitting radiofrequency radiation (RFR), a form of electromagnetic radiation (EMR). Consequently, ongoing researches target to determine whether it poses potential risks to human health. One of these risks is related with brain and auditory system. This study aims to examine the impact of acute and chronic exposure to 2100 MHz radiofrequency radiation on mismatch negativity (MMN) in rats. In this study, we established 1-week (RFR1) and 10-week (RFR10) RFR groups from rats, which were subjected to 2100 MHz RFR exposure. Cage control groups (CC1, CC10) and sham groups (S1, S10) that were not subjected to RFR for equivalent durations were also established. Following auditory event-related potential (AERP) recordings, MMN waves were computed and analyzed. Additionally, brain samples were collected and biochemical and histological analyses were performed. The RFR1 group exhibited a reduction in AMPAR GluR2 subunit protein levels relative to the CC1 and S1 groups, although GFAP protein levels increased. Conversely, the opposite was observed in the chronic groups. Edema of astrocytic endfeet, mitochondrial damage, and lysosomal vesicles were identified in the RFR1 group. The MMN amplitude was found to be reduced in the RFR1 group relative to the CC1 group. The RFR1 group exhibited a reduction in delta and theta power relative to the S1/CC1 groups. Alpha coherence diminished in the RFR1 group relative to the S1 group, however it augmented in the RFR10 group compared to the S10 group. The assessment of event-related potentials indicated that 2100 MHz RFR led to a decrease in MMN amplitude, power spectrum, and coherence values in the RFR1 group relative to the S1 and CC1 groups, but an increase was observed in the RFR10 group compared to the S10 group. Consequently, in the acute period, 2100 MHz RFR may have adverse effects on auditory sensory memory.

Ertilav K, Uslusoy F, Ataizi S, Nazıroğlu M.Long term exposure to cell phone frequencies (900 and 1800 MHz) induces apoptosis, mitochondrial oxidative stress and TRPV1 channel activation in the hippocampus and dorsal root ganglion of rats. Metab Brain Dis. 33(3):753-763, 2018.

Mobile phone providers use electromagnetic radiation (EMR) with frequencies ranging from 900 to 1800 MHz. The increasing use of mobile phones has been accompanied by several potentially pathological consequences, such as neurological diseases related to hippocampal (HIPPON) and dorsal root ganglion neuron (DRGN). The TRPV1 channel is activated different stimuli, including CapN, high temperature and oxidative stress. We investigated the contribution TRPV1 to mitochondrial oxidative stress and apoptosis in HIPPON and DRGN following long term exposure to 900 and 1800 MHz in a rat model. Twenty-four adult rats were equally divided into the following groups: (1) control, (2) 900 MHz, and (3) 1800 MHz exposure. Each experimental

group was exposed to EMR for 60 min/ 5 days of the week during the one year. The 900 and 1800 MHz EMR exposure induced increases in TRPV1 currents, intracellular free calcium influx (Ca^{2+}), reactive oxygen species (ROS) production, mitochondrial membrane depolarization (JC-1), apoptosis, and caspase 3 and 9 activities in the HIPPON and DRGN. These deleterious processes were further increased in the 1800 MHz experimental group compared to the 900 MHz exposure group. In conclusion, mitochondrial oxidative stress, programmed cell death and Ca^{2+} entry pathway through TRPV1 activation in the HIPPON and DRGN of rats were increased in the rat model following exposure to 900 and 1800 MHz cell frequencies. Our results suggest that exposure to 900 and 1800 MHz EMR may induce a dose-associated, TRPV1-mediated stress response.

Esmekaya MA, Aytekin E, Ozgur E, Güler G, Ergun MA, Omeroğlu S, Seyhan N. Mutagenic and morphologic impacts of 1.8GHz radiofrequency radiation on human peripheral blood lymphocytes (hPBLs) and possible protective role of pre-treatment with Ginkgo biloba (EGb 761). Sci Total Environ. 410-411:59-64, 2011.

The mutagenic and morphologic effects of 1.8GHz Global System for Mobile Communications (GSM) modulated RF (radiofrequency) radiation alone and in combination with Ginkgo biloba (EGb 761) pre-treatment in human peripheral blood lymphocytes (hPBLs) were investigated in this study using Sister Chromatid Exchange (SCE) and electron microscopy. Cell viability was assessed with 3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide (MTT) reduction assay. The lymphocyte cultures were exposed to GSM modulated RF radiation at 1.8GHz for 6, 8, 24 and 48h with and without EGb 761. We observed morphological changes in pulse-modulated RF radiated lymphocytes. Longer exposure periods led to destruction of organelle and nucleus structures. Chromatin change and the loss of mitochondrial crista occurred in cells exposed to RF for 8h and 24h and were more pronounced in cells exposed for 48h. Cytoplasmic lysis and destruction of membrane integrity of cells and nuclei were also seen in 48h RF exposed cells. There was a significant increase ($p<0.05$) in SCE frequency in RF exposed lymphocytes compared to sham controls. EGb 761 pre-treatment significantly decreased SCE from RF radiation. RF radiation also inhibited cell viability in a time dependent manner. The inhibitory effects of RF radiation on the growth of lymphoctes were marked in longer exposure periods. EGb 761 pre-treatment significantly increased cell viability in RF+EGb 761 treated groups at 8 and 24h when compared to RF exposed groups alone. The results of our study showed that RF radiation affects cell morphology, increases SCE and inhibits cell proliferation. However, EGb 761 has a protective role against RF induced mutagenity. We concluded that RF radiation induces chromosomal damage in hPBLs but this damage may be reduced by EGb 761 pre-treatment.

Falcioni, L., Bua, L., Tibaldi, E., Lauriola, M., De Angelis, L., Gnudi, F., Mandrioli, D., Manservigi, M., Manservisi, F., Manzoli, I., Menghetti, I., Montella, R., Panzacchi, S., Sgargi, D., Strollo, V., Vornoli, A., Belpoggi, F. Report of final results regarding brain and heart tumors in Sprague-Dawley rats exposed from prenatal life until natural death to mobile phone radiofrequency field representative of a 1.8 GHz GSM base station environmental emission. Environ Res. 165:496-503, 2018.

Background: In 2011, IARC classified radiofrequency radiation (RFR) as possible human carcinogen (Group 2B). According to IARC, animals studies, as well as epidemiological ones, showed limited evidence of carcinogenicity. In 2016, the NTP published the first results of its long-term bioassays on near field RFR, reporting increased incidence of malignant glial tumors of the brain and heart Schwannoma in rats exposed to GSM - and CDMA - modulated cell phone RFR. The tumors observed in the NTP study are of the type similar to the ones observed in some epidemiological studies of cell phone users. **Objectives:** The Ramazzini Institute (RI) performed a life-span carcinogenic study on Sprague-Dawley rats to evaluate the carcinogenic effects of RFR in the situation of far field, reproducing the environmental exposure to RFR generated by 1.8 GHz GSM antenna of the radio base stations of mobile phone. This is the largest long-term study ever performed in rats on the health effects of RFR, including 2448 animals. In this article, we reported the final results regarding brain and heart tumors. **Methods:** Male and female Sprague-Dawley rats were exposed from prenatal life until natural death to a 1.8 GHz GSM far field of 0, 5, 25, 50 V/m with a whole-body exposure for 19 h/day. **Results:** A statistically significant increase in the incidence of heart Schwannomas was observed in treated male rats at the highest dose (50 V/m). Furthermore, an increase in the incidence of heart Schwann cells hyperplasia was observed in treated male and female rats at the highest dose (50 V/m), although this was not statistically significant. An increase in the incidence of malignant glial tumors was observed in treated female rats at the highest dose (50 V/m), although not statistically significant. **Conclusions:** The RI findings on far field exposure to RFR are consistent with and reinforce the results of the NTP study on near field exposure, as both reported an increase in the incidence of tumors of the brain and heart in RFR-exposed Sprague-Dawley rats. These tumors are of the same histotype of those observed in some epidemiological studies on cell phone users. These experimental studies provide sufficient evidence to call for the re-evaluation of IARC conclusions regarding the carcinogenic potential of RFR in humans.

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Forgacs, Z., Somosy, Z., Kubinyi, G., Bakos, J., Hudak, A., Surjan, A., Thuroczy, G. Effect of whole-body 1800 MHz GSM-like microwave exposure on testicular steroidogenesis and histology in mice. Reprod Toxicol. 22:111-117, 2006.

The aim of our study was to evaluate the possible effects of whole-body 1800 MHz GSM-like microwave exposure on male reproduction. After repeated exposure of mice to microwaves at 0.018-0.023 W/kg whole-body specific energy absorption rate (SAR) an elevated serum testosterone level was measured, but no microwave exposure related histopathological alteration could be detected in the reproductive organs. The in vitro steroidogenic response of 48 h Leydig cell cultures obtained from exposed animals did not differ from the controls, suggesting that Leydig cells were not the primary targets of the applied microwave exposure or direct action of microwaves on Leydig cells was temporary only. In exposed animals the red blood cell count and volume of packed red cells were also increased. Further investigations are required to clarify the mechanism of action of the applied microwave exposure on male mice, as well as to establish the biological significance of the observed phenomena.

Furtado-Filho, O.V., Borba, J.B., Dallegrave, A., Pizzolato, T.M., Henriques, J.A., Moreira, J.C., Saffi, J. Effect of 950 MHz UHF electromagnetic radiation on biomarkers of oxidative

damage, metabolism of UFA and antioxidants in the livers of young rats of different ages. Int J Radiat Biol. 90:159-168, 2014.

Purpose: To assess the effect of 950 MHz ultra-high-frequency electromagnetic radiation (UHF EMR) on biomarkers of oxidative damage, as well as to verify the concentration of unsaturated fatty acids (UFA) and the expression of the catalase in the livers of rats of different ages. **Materials and methods:** Twelve rats were equally divided into two groups as controls (CR) and exposed (ER), for each age (0, 6, 15 and 30 days). Radiation exposure lasted half an hour per day for up to 51 days (21 days of gestation and 6, 15 or 30 days of life outside the womb). The specific absorption rate (SAR) ranged from 1.3-1.0 W/kg. The damage to lipids, proteins and DNA was verified by thiobarbituric acid reactive substances (TBARS), protein carbonyls and comets, respectively. UFA were determined by gas chromatography with a flame ionization detector. The expression of catalase was by Western blotting. **Results:** The neonates had low levels of TBARS and concentrations of UFA after exposure. There was no age difference in the accumulation of protein carbonyls for any age. The DNA damage of ER 15 or 30 days was different. The exposed neonates exhibited lower expression of catalase. **Conclusions:** 950 MHz UHF EMR does not cause oxidative stress (OS), and it is not genotoxic to the livers of neonates or those of 6 and 15 day old rats, but it changes the concentrations of polyunsaturated fatty acid (PUFA) in neonates. For rats of 30 days, no OS, but it is genotoxic to the livers of ER to total body irradiation.

Garaj-Vrhovac. V., Gajski, G., Pažanin, S., Sarolić, A., Domijan, A.M., Flajs. D., Peraica, M. Assessment of cytogenetic damage and oxidative stress in personnel occupationally exposed to the pulsed microwave radiation of marine radar equipment. Int J Hyg Environ Health. 4:59-65, 2011.

Due to increased usage of microwave radiation, there are concerns of its adverse effect in today's society. Keeping this in view, study was aimed at workers occupationally exposed to pulsed microwave radiation, originating from marine radars. Electromagnetic field strength was measured at assigned marine radar frequencies (3 GHz, 5.5 GHz and 9.4 GHz) and corresponding specific absorption rate values were determined. Parameters of the comet assay and micronucleus test were studied both in the exposed workers and in corresponding unexposed subjects. Differences between mean tail intensity (0.67 vs. 1.22) and moment (0.08 vs. 0.16) as comet assay parameters and micronucleus test parameters (micronuclei, nucleoplasmic bridges and nuclear buds) were statistically significant between the two examined groups, suggesting that cytogenetic alterations occurred after microwave exposure. Concentrations of glutathione and malondialdehyde were measured spectrophotometrically and using high performance liquid chromatography. The glutathione concentration in exposed group was significantly lower than in controls (1.24 vs. 0.53) whereas the concentration of malondialdehyde was significantly higher (1.74 vs. 3.17), indicating oxidative stress. Results suggests that pulsed microwaves from working environment can be the cause of genetic and cell alterations and that oxidative stress can be one of the possible mechanisms of DNA and cell damage.

Gautam R, Pardhiya S, Nirala JP, Sarsaiya P, Rajamani P. Effects of 4G mobile phone radiation exposure on reproductive, hepatic, renal, and hematological parameters of male Wistar rat. Environ Sci Pollut Res Int 31(3):4384-4399, 2024.

Background and objective: Mobile phones have become a vital part of human life. Due to drastic increase in the number of mobile phone subscribers, exposure to radiofrequency radiation (RFR) emitted from these phones has increased dramatically. Hence, the effect of RFR on humans is an area of concern. This study was performed to determine the impact of 4G mobile phone radiation on the male reproductive system, liver, kidney, and hematological parameters. **Methods:** Seventy-day-old Wistar rats were exposed to 4G radiation (2350 MHz for 2 h/day for 56 days). Sperm parameters such as sperm count, viability, sperm head morphology, mitochondrial activity, total antioxidant activity, and lipid peroxidation of sperm were evaluated. Histopathology of the testis, prostate, epididymis, seminal vesicle, liver, and kidney was carried out. Complete blood count, liver and kidney function tests, and testosterone hormone analysis were done. **Results:** At the end of the experiment, results showed a significant ($p < 0.05$) decrease in sperm viability with alterations in the histology of the liver, kidney, testis, and other reproductive organs in the exposed group of rats. A reduced level of testosterone, total antioxidant capacity, and decreased sperm mitochondrial function were also observed in the exposed rats. Moreover, the exposed rats showed an increase in sperm lipid peroxidation and sperm abnormality. Hematological parameters like hemoglobin, red blood cells (RBC), and packed cell volume (PCV) showed a significant ($p < 0.05$) increase in the exposed rats. **Conclusion:** The results indicate that chronic exposure to 4G radiation may affect the male reproductive system, hematological system, liver, and kidney of rats.

Gautam R, Jha N, Tomar AK, Nirala JP, Arora T, Rajamani P. Oxidative stress and testicular damage induced by chronic exposure to 35.5 GHz millimeter wave radiation in male Wistar rats. Andrology. 2025 Aug 12. doi: 10.1111/andr.70107.

Background: The widespread usage of millimeter waves (MMW) in different spheres of the public domain necessitates to have a better understanding of any possible health impacts caused by them. The latest example of this is the global implementation of 5G technology.
Objectives: The present investigation aimed to study the effects of 35.5 GHz frequency on reproductive parameters of male Wistar rats. Methods: The study employed a randomized controlled design, with animals being assigned to control, sham-exposed, and exposed groups, with six animals in each group ($n = 6$). The experimental group was exposed to 35.5 GHz frequency for 2 h per day for 60 days. At the end of the exposure period, various sperm parameters such as sperm count, morphology, viability, and sperm mitochondrial activity were evaluated. The evaluation of oxidative stress was done by lipid peroxidation assay in testis homogenate. Superoxide dismutase, total sulfhydryl level, and total antioxidant capacity were assessed in testis homogenate. The DNA damage in the testis was assessed through the comet assay. Results: The results showed a significant decrease in sperm viability and count, as well as morphometric changes in testis histopathology. Lipid peroxidation testis was significantly elevated in the exposed group, while superoxide dismutase (SOD), total sulfhydryl level, and total antioxidant capacity were significantly decreased in the exposed group. The comet assay revealed a significant increase in DNA damage in the exposed group, indicating genotoxic effects. Discussion: The observed changes in sperm parameters, testicular morphology, and

oxidative stress markers highlight the potential for testicular tissue damage via oxidative mechanisms. These results underscore the need for further research to elucidate the biological implications of chronic MMW exposure. Conclusion: Chronic exposure to 35.5 GHz frequency may negatively impact male reproductive function and testicular tissue, primarily through mechanisms involving oxidative stress.

Gelenli Dolanbay E, Mert T, Caliskan Bender G, Bektas H, Uslu U, Fernandez-Rodriguez CE, Dasdag S. Male Reproductive and Cellular Damage After Prenatal 3.5 GHz Radiation Exposure: One-Year Postnatal Effects. Ann N Y Acad Sci. 2025 Oct 23. doi: 10.1111/nyas.70116. Epub ahead of print.

This study investigates the long-term effects of prenatal exposure to 3.5 GHz radiofrequency radiation (RFR) on male reproductive health. Pregnant Wistar Hannover rats were divided into sham control, full-gestation exposure (3T RFR), and late-gestation exposure (2T RFR) groups (2 h/day). Male offspring were euthanized at 12 months for testicular analysis. In the 3T RFR group, seminiferous tubule diameter and epithelial height were significantly reduced compared to controls (adjusted $p = 0.03$ and 9.71×10^{-8}), along with lower Johnsen scores (adjusted $p = 0.022$). Abnormal sperm morphology increased significantly (adjusted $p = 0.036$). γ-H2AX immunostaining scores were elevated in the 2T and 3T groups (adjusted $p = 0.012$ and 6.36×10^{-9}). Beclin-1 expression was significantly higher in the 3T group versus sham and 2T groups (adjusted $p = 8.55 \times 10^{-4}$ and 4.51×10^{-6}). TUNEL-positive cell counts were significantly higher in both RFR groups than in sham (adjusted $p = 8.77 \times 10^{-18}$ for 3T, 6.42×10^{-17} for 2T), as was the apoptosis index (adjusted $p = 8.77 \times 10^{-18}$ for 3T, 5.66×10^{-17} for 2T). All p values were Holm-Bonferroni corrected. These findings indicate that prenatal exposure to 3.5 GHz RFR results in persistent testicular damage, impaired spermatogenesis, and increased DNA damage, autophagy, and apoptosis in adult male rats.

Ghazizadeh V, Nazıroğlu M. Electromagnetic radiation (Wi-Fi) and epilepsy induce calcium entry and apoptosis through activation of TRPV1 channel in hippocampus and dorsal root ganglion of rats. Metab Brain Dis. 29(3):787-799, 2014.

Incidence rates of epilepsy and use of Wi-Fi worldwide have been increasing. TRPV1 is a Ca^{2+} permeable and non-selective channel, gated by noxious heat, oxidative stress and capsaicin (CAP). The hyperthermia and oxidant effects of Wi-Fi may induce apoptosis and Ca^{2+} entry through activation of TRPV1 channel in epilepsy. Therefore, we tested the effects of Wi-Fi (2.45 GHz) exposure on Ca^{2+} influx, oxidative stress and apoptosis through TRPV1 channel in the murine dorsal root ganglion (DRG) and hippocampus of pentylentetrazol (PTZ)-induced epileptic rats. Rats in the present study were divided into two groups as controls and PTZ. The PTZ groups were divided into two subgroups namely PTZ + Wi-Fi and PTZ + Wi-Fi + capsazepine (CPZ). The hippocampal and DRG neurons were freshly isolated from the rats. The DRG and hippocampus in PTZ + Wi-Fi and PTZ + Wi-Fi + CPZ groups were exposed to Wi-Fi for 1 hour before CAP stimulation. The cytosolic free Ca^{2+}, reactive oxygen species production, apoptosis, mitochondrial membrane depolarization, caspase-3 and -9 values in hippocampus were higher in the PTZ group than in the control although cell viability values decreased. The Wi-Fi exposure induced additional effects on the cytosolic Ca^{2+} increase. However, pretreatment

of the neurons with CPZ, results in a protection against epilepsy-induced Ca^{2+} influx, apoptosis and oxidative damages. In results of whole cell patch-clamp experiments, treatment of DRG with Ca^{2+} channel antagonists [thapsigargin, verapamil + diltiazem, 2-APB, MK-801] indicated that Wi-Fi exposure induced Ca^{2+} influx via the TRPV1 channels. In conclusion, epilepsy and Wi-Fi in our experimental model is involved in Ca^{2+} influx and oxidative stress-induced hippocampal and DRG death through activation of TRPV1 channels, and negative modulation of this channel activity by CPZ pretreatment may account for the neuroprotective activity against oxidative stress.

Gökçek-Saraç, Ç, Er, H., Kencebay Manas, C., Kantar Gok, D., Özen, Ş., Derin, N. Effects of acute and chronic exposure to both 900 MHz and 2100 MHz electromagnetic radiation on glutamate receptor signaling pathway. Int J Radiat Biol. 93:980-989, 2017.

Purpose: To demonstrate the molecular effects of acute and chronic exposure to both 900 and 2100 MHz radiofrequency electromagnetic radiation (RF-EMR) on the hippocampal level/activity of some of the enzymes - including PKA, CaMKIIα, CREB, and p44/42 MAPK - from N-methyl-D-aspartate receptor (NMDAR)-related signaling pathways. **Materials and methods:** Rats were divided into the following groups: sham rats, and rats exposed to 900 and 2100 MHz RF-EMR for 2 h/day for acute (1 week) or chronic (10 weeks), respectively. Western blotting and activity measurement assays were used to assess the level/activity of the selected enzymes.**Results:** The obtained results revealed that the hippocampal level/activity of selected enzymes was significantly higher in the chronic groups as compared to the acute groups at both 900 and 2100 MHz RF-EMR exposure. In addition, hippocampal level/activity of selected enzymes was significantly higher at 2100 MHz RF-EMR than 900 MHz RF-EMR in both acute and chronic groups. **Conclusions:** The present study provides experimental evidence that both exposure duration (1 week versus 10 weeks) and different carrier frequencies (900 vs. 2100 MHz) had different effects on the protein expression of hippocampus in Wistar rats, which might encourage further research on protection against RF-EMR exposure.

Grémiaux, A., Girard, S., Guérin, V., Lothier, J., Baluška, F., Davies, E., Bonnet, P., Vian, A. Low-amplitude, high-frequency electromagnetic field exposure causes delayed and reduced growth in Rosa hybrida. J Plant Physiol. 190:44-53, 2016.

It is now accepted that plants perceive high-frequency electromagnetic field (HF-EMF). We wondered if the HF-EMF signal is integrated further in planta as a chain of reactions leading to a modification of plant growth. We exposed whole small ligneous plants (rose bush) whose growth could be studied for several weeks. We performed exposures at two different development stages (rooted cuttings bearing an axillary bud and 5-leaf stage plants), using two high frequency (900MHz) field amplitudes (5 and 200Vm(-1)). We achieved a tight control on the experimental conditions using a state-of-the-art stimulation device (Mode Stirred Reverberation Chamber) and specialized culture-chambers. After the exposure, we followed the shoot growth for over a one-month period. We observed no growth modification whatsoever exposure was performed on the 5-leaf stage plants. When the exposure was performed on the rooted cuttings, no growth modification was observed on Axis I (produced from the elongation of the axillary bud).

Likewise, no significant modification was noted on Axis II produced at the base of Axis I, that came from pre-formed secondary axillary buds. In contrast, Axis II produced at the top of Axis I, that came from post-formed secondary buds consistently displayed a delayed and significant reduced growth (45%). The measurements of plant energy uptake from HF-EMF in this exposure condition (SAR of 7.2 10(-4)Wkg(-1)) indicated that this biological response is likely not due to thermal effect. These results suggest that exposure to electromagnetic field only affected development of post-formed organs.

Grigor'ev IuG, Mikhaĭlov VF, Ivanov AA, Mal'tsev VN, Ulanova AM, Stavrakova NM, Nikolaeva IA, Grigor'ev OA. [Autoimmune processes after long-term low-level exposure to electromagnetic fields (the results of an experiment). Part 4. Manifestation of oxidative intracellular stress-reaction after long-term non-thermal EMF exposure of rats] Radiats Biol Radioecol. 50(1):22-27, 2010. [Article in Russian]

This paper presents the results of the study of the effects of long-term low-level exposure of rats to microwaves. Rats were exposed in far field to 2450 MHz continuous wave fields providing an incident power density at the cages of 500 microW/cm2 for 7 hours daily for a total of 30 days resulting in a whole-body SAR of 0.16 +/- 0.04 W/kg. Three groups ("EMF-exposure", "sham-exposure" and cage-control) were formed, each consisting of 16 rats. Circulating antibodies (IgA, IgG and IgM) directed against 16 chemical substances were evaluated in coded serum from each group of rats by enzyme multiplied analysis (ELISA test). An increased amount of compounds resulting from interaction of amino acids with nitric oxide (NO) or its derivatives (NO2-Tyrosine, NO-Arginine, NO-Cysteine + NO-Bovine Serum Albumin, NJ-Methionine + NO-Asparagine + No-Histidine, NO-BTrypnohan + NJ-Tyrosin), fatty acids with small chains, hydroxylated fatty acids, palmitic/myristic/oleic acid, AZE (product of oxidation of fatty acids) was found in blood serum from EMF-exposed rats. As a rule, antibodies to conjugated antigens were seen for IgM, rarely seen for IgG and were completely absent for IgA. The levels of antibodies were higher on day 7 after the exposure compared to those on day 14 after the exposure.

Gulati, S., Kosik, P., Durdik, M., Skorvaga, M., Jakl, L., Markova, E., Belyaev, I. Effects of different mobile phone UMTS signals on DNA, apoptosis and oxidative stress in human lymphocytes. Environ Pollut. 267:115632, 2020.

Different scientific reports suggested link between exposure to radiofrequency radiation (RF) from mobile communications and induction of reactive oxygen species (ROS) and DNA damage while other studies have not found such a link. However, the available studies are not directly comparable because they were performed at different parameters of exposure, including carrier frequency of RF signal, which was shown to be a critical for appearance of the RF effects. For the first time, we comparatively analyzed genotoxic effects of UMTS signals at different frequency channels used by 3G mobile phones (1923, 1947.47, and 1977 MHz). Genotoxicity was examined in human lymphocytes exposed to RF for 1 h and 3 h using complimentary endpoints such as induction of ROS by imaging flow cytometry, DNA damage by alkaline comet assay, mutations in TP53 gene by RSM assay, preleukemic fusion genes (PFG) by RT-qPCR, and apoptosis by flow cytometry. No effects of RF exposure on ROS, apoptosis, PFG, and mutations in TP53 gene were revealed regardless the UMTS frequency while inhibition of a bulk

RNA expression was found. On the other hand, we found relatively small but statistically significant induction of DNA damage in dependence on UMTS frequency channel with maximal effect at 1977.0 MHz. Our data support a notion that each specific signal used in mobile communication should be tested in specially designed experiments to rule out that prolonged exposure to RF from mobile communication would induce genotoxic effects and affect the health of human population.

Güler G, Ozgur E, Keles H, Tomruk A, Vural SA, Seyhan N. Neurodegenerative changes and apoptosis induced by intrauterine and extrauterine exposure of radiofrequency radiation. J Chem Neuroanat 75(Pt B):128-133, 2016.

Adverse health effects of radiofrequency radiation (RFR) on the ongoing developmental stages of children from conception to childhood are scientifically anticipated subject. This study was performed to identify the effects of global system for mobile communications (GSM) modulated mobile phone like RFR in 1800MHz frequency on oxidative DNA damage and lipid peroxidation beside the apoptotic cell formation, using histopathological and immunohistochemical methods in the brain tissue of 1-month-old male and female New Zealand White rabbits that were exposed to these fields at their mother's womb and after the birth. Oxidative DNA damage and lipid peroxidation levels were investigated by measuring the 8-hydroxy-2'-deoxyguanosine (8-OHdG) and malondialdehyde (MDA) levels, respectively. Histopathological changes were observed using by hematoxylin and eosin (HE) staining. Apoptotic cells were detected in the examined organs by terminal deoxynucleotidyl transferase-mediated dUTP nick end-labeling (TUNEL) staining. For both male and female infants; 8-OHdG levels increased in the group exposed to RFR in both intrauterine and extrauterine periods compared to the infants that were never exposed to RFR and the ones were exposed when they reached one month of age ($p<0.05$). MDA results were different for male and female rabbits. There was no difference between all female infant groups ($p>0.05$), while only intrauterine exposure significantly causes MDA level increase for the male infants. HE staining revealed mild lessions in neuronal necrobiosis in brain tissues of female rabbits that had only intaruterine exposure and male rabbits had only extrauterine exposure. Gliosis were mildly positive in brain tissues of rabbits that are exposed only intrauterine period, also the group exposed both intrauterine and extrauterine periods. However, there was no apoptotic change detected by TUNEL staining in the brain tissues of all groups.

Gupta, S.K., Mesharam, M.K., Krishnamurthy, S. Electromagnetic radiation 2450 MHz exposure causes cognition deficit with mitochondrial dysfunction and activation of intrinsic pathway of apoptosis in rats. J Biosci. 43:263-276, 2018.

Electromagnetic radiation (EMR) can induce or modulate several neurobehavioral disorders. Duration and frequency of exposure of EMR is critical to develop cognitive disorders. Even though EMR-2450 is widely used, its effects on cognition in relation to mitochondrial function and apoptosis would provide better understanding of its pathophysiological effects. Therefore, a comparative study of different frequencies of EMR exposure would give valuable information on effects of discrete frequencies of EMR on cognition. Male rats were exposed to EMR (900, 1800 and 2450 MHz) every day for 1 h for 28 consecutive days. The cognitive behavior in terms of

novel arm entries in Y-maze paradigm was evaluated every week after 1 h to last EMR exposure. Animals exposed to EMR-2450 MHz exhibited significant cognitive deficits. EMR- 2450 MHz caused loss of mitochondrial function and integrity, an increase in amyloid beta expression. There was release of cytochrome-c and activation of apoptotic factors such as caspase-9 and -3 in the hippocampus. Further, there was decrease in levels of acetylcholine, and increase in activity of acetyl cholinesterase, indicating impairment of cholinergic system. Therefore, exposure of EMR-2450 in rats caused cognitive deficit with related pathophysiological changes in mitochondrial and cholinergic function, and amyloidogenesis.

Gürler HS, Bilgici B, Akar AK, Tomak L, Bedir A. Increased DNA oxidation (8-OHdG) and protein oxidation (AOPP) by Low level electromagnetic field (2.45 GHz) in rat brain and protective effect of garlic. Int J Radiat Biol. 90:892-896, 2014.

Purpose: To investigate the oxidative damage and protective effect of garlic on rats exposed to low level of electromagnetic fields (EMF) at 2.45 GHz Microwave radiation (MWR). Methods: Thirty six Wistar rats were divided into three groups. Group I was the control group and not exposed to EMF. Group II and III were exposed to low level EMF (3.68±0.36 V/m) at 2.45 GHz MWR for 1 hour/day for 30 consecutive days. Daily 500 mg/kg garlic was given to Group III during the study period. At the end of the study, thiobarbituric acid reactive substances (TBARS), advanced oxidation protein products (AOPP) and 8-hydroxydeoxyguanosine (8-OHdG) levels were investigated in brain tissue and blood samples. Results: Exposure to low level of EMF increased 8-OHdG level in both plasma and brain tissue whereas it increased AOPP level only in plasma. Garlic prevented the increase of 8-OHdG level in brain tissue and plasma AOPP levels. Conclusions: It may be concluded that low level EMF at 2.45 GHz MWR increases the DNA damage in both brain tissues and plasma of the rats whereas it increases protein oxidation only in plasma. It may also be argued that the use of garlic decreases these effects.

Halgamuge, M.N., Yak, S.K., Eberhardt, J.L. Reduced growth of soybean seedlings after exposure to weak microwave radiation from GSM 900 mobile phone and base station. Bioelectromagnetics. 36:87-95, 2015.

The aim of this work was to study possible effects of environmental radiation pollution on plants. The association between cellular telephone (short duration, higher amplitude) and base station (long duration, very low amplitude) radiation exposure and the growth rate of soybean (Glycine max) seedlings was investigated. Soybean seedlings, pre-grown for 4 days, were exposed in a gigahertz transverse electromagnetic cell for 2 h to global system for mobile communication (GSM) mobile phone pulsed radiation or continuous wave (CW) radiation at 900 MHz with amplitudes of 5.7 and 41 V m(-1) , and outgrowth was studied one week after exposure. The exposure to higher amplitude (41 V m(-1)) GSM radiation resulted in diminished outgrowth of the epicotyl. The exposure to lower amplitude (5.7 V m(-1)) GSM radiation did not influence outgrowth of epicotyl, hypocotyls, or roots. The exposure to higher amplitude CW radiation resulted in reduced outgrowth of the roots whereas lower CW exposure resulted in a reduced outgrowth of the hypocotyl. Soybean seedlings were also exposed for 5 days to an extremely low level of radiation (GSM 900 MHz, 0.56 V m(-1)) and outgrowth was studied 2 days later. Growth of epicotyl and hypocotyl was found to be reduced, whereas the outgrowth of roots was

stimulated. Our findings indicate that the observed effects were significantly dependent on field strength as well as amplitude modulation of the applied field.

Hancı H, Odacı E, Kaya H, Aliyazıcıoğlu Y, Turan I, Demir S, Colakoğlu S. The effect of prenatal exposure to 900-MHz electromagnetic field on the 21-old-day rat testicle. Reprod Toxicol. 42:203-209, 2013.

The aim of this study was to investigate the effect of exposure to a 900-MHz electromagnetic field (EMF) in the prenatal term on the 21-old-day rat testicle. Pregnant rats were divided into control (CG) and EMF (EMFG) groups. EMFG was exposed to 900-MHz EMF during days 13-21 of pregnancy. Newborn CG rats were obtained from the CG and newborn EMFG (NEMFG) rats from the EMFG. Testicles were extracted at postnatal day 21. Lipid peroxidation and DNA oxidation levels, apoptotic index and histopathological damage scores were compared. NEMFG rats exhibited irregularities in seminiferous tubule basal membrane and epithelium, immature germ cells in the lumen, and a decreased diameter in seminiferous tubules and thickness of epithelium. Apoptotic index, lipid peroxidation and DNA oxidation were higher in NEMFG rats than in NCG. 21-day-old rat testicles exposed to 900-MHz EMF in the prenatal term may be adversely affected, and this effect persists after birth

Hancı H, Türedi S, Topal Z, Mercantepe T, Bozkurt I, Kaya H, Ersöz Ş, Ünal B, Odacı E. Can prenatal exposure to a 900 MHz electromagnetic field affect the morphology of the spleen and thymus, and alter biomarkers of oxidative damage in 21-day-old male rats? Biotech Histochem. 90(7):535-543, 2015.

We investigated the effects of a 900 Megahertz (MHz) electromagnetic field (EMF), applied during the prenatal period, on the spleen and thymus of 21-day-old male rat pups. Pregnant Sprague-Dawley rats were divided into control and EMF groups. We applied 900 MHz EMF for 1 h/day to the EMF group of pregnant rats. Newborn male rat pups were removed from their mothers and sacrificed on postnatal day 21. Spleen and thymus tissues were excised and examined. Compared to the control group, thymus tissue malondialdehyde levels were significantly higher in the group exposed to EMF, while glutathione levels were significantly decreased. Increased malondialdehyde and glutathione levels were observed in splenic tissue of rats exposed to EMF, while a significant decrease occurred in superoxide dismutase values compared to controls. Transmission electron microscopy showed pathological changes in cell morphology in the thymic and splenic tissues of newborn rats exposed to EMF. Exposure to 900 MHz EMF during the prenatal period can cause pathological and biochemical changes that may compromise the development of the male rat thymus and spleen.

Hancı, H., Kerimoğlu, G., Mercantepe, T., Odacı, E. Changes in testicular morphology and oxidative stress biomarkers in 60-day-old Sprague Dawley rats following exposure to continuous 900-MHz electromagnetic field for 1 h a day throughout adolescence. Reprod Toxicol. 81:71-78. 2018.

The purpose of this study was to investigate the 60-day-old male rat testis following exposure to continuous 900-megahertz (MHz) electromagnetic field (EMF) throughout the adolescent period using histopathological and biochemical analysis methods. Twenty-four Sprague Dawley rats

aged 21 days were randomly and equally (n = 8) divided into three groups. No procedure was performed on the control group rats. The sham group rats were held in an EMF-cage without exposure to EMF. The EMF group rats were exposed to continuous 900-MHz EMF for 1 h each day inside the EMF-cage during adolescence. On postnatal day 60 the testes were extracted and divided into right and left halves. The right half was used for histopathological evaluation and the left half for biochemical analyses. Our results show that changes may occur in morphology and oxidative stress biomarkers in the rat testis following exposure to continuous 900-MHz EMF throughout the adolescent period.

Hancı H, Yenilmez E, Demir S, Yıldırım M, Gedikli Ö, Kaya H. The effect on rat peripheral nerve morphology and function of a 900-MHz electromagnetic field applied in the prenatal period. Electromagn Biol Med 2025 Mar 18:1-16. doi: 10.1080/15368378.2025.2479517. Online ahead of print

The purpose of this study was to investigate the effects of a 900 megahertz (MHz) electromagnetic field (EMF) applied in the prenatal period on rat peripheral nerve morphology, nerve conduction velocity, and locomotor activity. Nine pregnant Sprague Dawley rats were assigned into three groups. No procedure was applied to the first group (control). The second (sham) group was placed inside an EMF cage for 1 h a day throughout the experiment (days 1-21 of pregnancy), but was not exposed to EMF. The third group (EMF) was placed inside the EMF cage for 1 h a day throughout the experiment (days 1-21 of pregnancy) and exposed to a 900 MHz EMF. No procedure was applied to the newborn pups until postnatal (PN) day 21, and new groups were constituted from among these. All the newly established groups were subjected to the open field and rotarod tests on PN days 21 and 60, after which electrophysiological measurements were performed on the groups in line with the study protocol. Sciatic nerves obtained from the animals sacrificed on PN day 60 were subjected to histopathological, histomorphometric, immunohistochemical, and biochemical analyses. In light of the study results, we concluded that prenatal application of a 900 MHz EMF adversely affects rat peripheral nerve development, and that these effects persist up to adulthood such as to be detectable in the sciatic nerve morphology, but that these morphological changes are not sufficiently severe to affect functional associated with the sciatic nerve.

Hatice Ş. Gürler, Birşen Bilgici, Ayşegül K. Akar, Leman Tomak & Abdülkerim Bedir. Increased DNA oxidation (8-OHdG) and protein oxidation (AOPP) by low level electromagnetic field (2.45 GHz) in rat brain and protective effect of garlic. International Journal of Radiation Biology 90(10):892-896, 2014.

Purpose: To investigate the oxidative damage and protective effect of garlic on rats exposed to low level of electromagnetic fields (EMF) at 2.45 GHz Microwave radiation (MWR). *Methods*: Thirty-six Wistar rats were divided into three groups. Group I was the control group and not exposed to EMF. Group II and III were exposed to low level EMF (3.68 ± 0.36 V/m) at 2.45 GHz MWR for 1 hour/day for 30 consecutive days. Daily 500 mg/kg garlic was given to Group III during the study period. At the end of the study, thiobarbituric acid reactive substances (TBARS), advanced oxidation protein products (AOPP) and 8-hydroxydeoxyguanosine (8-OHdG) levels were investigated in brain tissue and blood samples. *Results*: Exposure to low level of EMF increased 8-OHdG level in both plasma and brain tissue whereas it increased

AOPP level only in plasma. Garlic prevented the increase of 8-OHdG level in brain tissue and plasma AOPP levels. *Conclusions*: It may be concluded that low level EMF at 2.45 GHz MWR increases the DNA damage in both brain tissues and plasma of the rats whereas it increases protein oxidation only in plasma. It may also be argued that the use of garlic decreases these effects.

He, Q., Sun,Y., Zong, L., Tong, J., Cao, Y. Induction of poly(ADP-ribose) polymerase in mouse bone marrow stromal cells exposed to 900 MHz radiofrequency fields: Preliminary observations. Biomed Res Int. 2016:4918691, 2016.

Background. Several investigators have reported increased levels of poly(ADP-ribose) polymerase-1 (PARP-1), a nuclear enzyme which plays an important role in the repair of damaged DNA, in cells exposed to extremely low dose ionizing radiation which does not cause measurable DNA damage. Objective. To examine whether exposure of the cells to nonionizing radiofrequency fields (RF) is capable of increasing messenger RNA of PARP-1 and its protein levels in mouse bone marrow stromal cells (BMSCs). Methods. BMSCs were exposed to 900 MHz RF at 120 μW/cm(2) power intensity for 3 hours/day for 5 days. PARP-1 mRNA and its protein levels were examined at 0, 0.5, 1, 2, 4, 6, 8, and 10 hours after exposure using RT-PCR and Western blot analyses. Sham-exposed (SH) cells and those exposed to ionizing radiation were used as unexposed and positive control cells. Results. BMSCs exposed to RF showed significantly increased expression of PARP-1 mRNA and its protein levels after exposure to RF while such changes were not observed in SH-exposed cells. Conclusion. Nonionizing RF exposure is capable of inducing PARP-1.

He Q, Zong L, Sun Y, Vijayalaxmi , Prihoda TJ, Tong J, Cao Y. Adaptive response in mouse bone marrow stromal cells exposed to 900 MHz radiofrequency fields: Impact of poly (ADP-ribose) polymerase (PARP). Mutat Res Genet Toxicol Environ Mutagen 820:19-25, 2017.

This study examined whether non-ionizing radiofrequency fields (RF) exposure is capable of inducing poly (ADP-ribose) polymerase-1 (PARP-1) in bone marrow stromal cells (BMSCs) and whether it plays a role in RF-induced adaptive response (AR). Bone marrow stromal cells (BMSCs) were exposed to 900MHz RF at 120μW/cm2 power flux density for 3h/day for 5days and then challenged with a genotoxic dose of 1.5Gy gamma-radiation (GR). Some cells were also treated with 3-aminobenzamide (3-AB, 2mM final concentration), a potent inhibitor of PARP-1. Un-exposed and sham (SH)-exposed control cells as well as positive control cells exposed to gamma radiation (GR) were included in the experiments. The expression of PARP-1 mRNA and its protein levels as well as single strand breaks in the DNA and the kinetics of their repair were evaluated at several times after exposures. The results indicated the following. (a) Cells exposed to RF alone showed significantly increased PARP-1 mRNA expression and its protein levels compared with those exposed to SH- and GR alone. (b) Treatment of RF-exposed cells with 3-AB had diminished such increase in PARP-1. (c) Cells exposed to RF+GR showed significantly decreased genetic damage as well as faster kinetics of repair compared with those exposed to GR alone. (d) Cells exposed to RF+3-AB+GR showed no such decrease in genetic

damage. Thus, the overall date suggested that non-ionizing RF exposure was capable of inducing PARP-1 which has a role in RF-induced AR.

Hekmat, A., Saboury, A.A., Moosavi-Movahedi, A.A. The toxic effects of mobile phone radiofrequency (940 MHz) on the structure of calf thymus DNA. Ecotoxicol Environ Saf. 88:35-41, 2013.

Currently, the biological effects of nonionizing electromagnetic fields (EMFs) including radiofrequency (RF) radiation have been the subject of numerous experimental and theoretical studies. The aim of this study is to evaluate the possible biological effects of mobile phone RF (940 MHz, 15 V/m and SAR=40 mW/kg) on the structure of calf thymus DNA (ct DNA) immediately after exposure and 2 h after 45 min exposure via diverse range of spectroscopic instruments. The UV-vis and circular dichroism (CD) experiments depict that mobile phone EMFs can remarkably cause disturbance on ct DNA structure. In addition, the DNA samples, immediately after exposure and 2 h after 45 min exposure, are relatively thermally unstable compared to the DNA solution, which was placed in a small shielded box (unexposed ct DNA). Furthermore, the exposed DNA samples (the DNA samples that were exposed to 940 MHz EMF) have more fluorescence emission when compared with the unexposed DNA, which may have occurred attributable to expansion of the exposed DNA structure. The results of dynamic light scattering (DLS) and zeta potential experiments demonstrate that RF-EMFs lead to increment in the surface charge and size of DNA. The structure of DNA immediately after exposure is not significantly different from the DNA sample 2 h after 45 min exposure. In other words, the EMF-induced conformational changes are irreversible. Collectively, our results reveal that 940 MHz can alter the structure of DNA. The displacement of electrons in DNA by EMFs may lead to conformational changes of DNA and DNA disaggregation. Results from this study could have an important implication on the health effects of RF-EMFs exposure. In addition, this finding could proffer a novel strategy for the development of next generation of mobile phone.

(E) Hidisoglu E, Kantar-Gok D, Ozen S, Yargicoglu P. Short-term 2.1 GHz radiofrequency radiation treatment induces significant changes on the auditory evoked potentials in adult rats. Int J Radiat Biol 94(9):858-871, 2018. (VO, CE, LI, IOD)

Purpose: There is a growing interest in the usage of radiofrequency radiation (RF) as a noninvasive brain stimulation method. Previously reported data demonstrated that RF exposure caused a change in brain oscillations. Therefore, we aimed to investigate effects of RF on brain oscillation by measuring the auditory response of different brain regions in rats. **Materials and methods:** Rats were randomly divided into three groups (n = 12 per each group): Cage control (C), sham rats (Sh), and rats exposed to 2.1 GHz RF for 2 h/day for 7 days. At the end of the exposure, auditory evoked potentials (AEPs) were recorded at different locations in rats. Latencies and amplitudes of AEPs, evoked power, inter-trial phase synchronization, and auditory evoked gamma responses were obtained in response to an auditory stimulus. Furthermore, TBARS levels and 4-HNE, GFAP, iNOS, and nNOS expressions were evaluated in all groups. **Results:** Peak-to-peak amplitudes of AEPs were significantly higher in the RF group compared with the Sh group. There is no significant difference in peak latencies of AEPs between groups. Beside, evoked power, inter-trial phase synchronization, and auditory evoked gamma responses were significantly higher in the RF group compared with the Sh group. In addition, the RF group

had significantly lower TBARS and 4-HNE levels than the Sh group. There were no significant differences between groups for GFAP, nNOS, and iNOS levels, and between the C and RF groups for all parameters. **Conclusions:** Our present findings suggest that short-term RF treatment under chosen experimental conditions have statistically significant effect on neuronal networks of rats by probably reducing oxidative damage. However, this effect must be further studied for possible noninvasive brain stimulation.

Ivaschuk, O.I., Jones, R.A., Ishida-Jones, T., Haggren, W., Adey, W.R., Phillips, J.L. Exposure of nerve growth factor-treated PC12 rat pheochromocytoma cells to a modulated radiofrequency field at 836.55 MHz: effects on c-jun and c-fos expression. Bioelectromagnetics. 18:223-229, 1997.

Rat PC12 pheochromocytoma cells have been treated with nerve growth factor and then exposed to athermal levels of a packet-modulated radiofrequency field at 836.55 MHz. This signal was produced by a prototype time-domain multiple-access (TDMA) transmitter that conforms to the North American digital cellular telephone standard. Three slot average power densities were used: 0.09, 0.9, and 9 mW/cm2. Exposures were for 20, 40, and 60 min and included an intermittent exposure regimen (20 min on/20 min off), resulting in total incubation times of 20, 60, and 100 min, respectively. Concurrent controls were sham exposed. After extracting total cellular RNA, Northern blot analysis was used to assess the expression of the immediate early genes, c-fos and c-jun, in all cell populations. No change in c-fos transcript levels were detected after 20 min exposure at each field intensity (20 min was the only time period at which c-fos message could be detected consistently). Transcript levels for c-jun were altered only after 20 min exposure to 9 mW/cm2 (average 38% decrease).

Jech, R., Sonka, K., Ruzicka, E., Nebuzelsky, A., Bohm, J., Juklickova, M., Nevsimalova, S. Electromagnetic field of mobile phones affects visual event related potential in patients with narcolepsy. Bioelectromagnetics. 22: 519-528, 2001.

The effects of the mobile phone (MP) electromagnetic fields on electroencephalography (EEG) and event-related potentials (ERP) were examined. With regard to the reported effects of MP on sleep, 22 patients with narcolepsy-cataplexy were exposed or sham exposed for 45 min to the MP (900 MHz, specific absorption rate 0.06 W/kg) placed close to the right ear in a double blind study. There were no changes of the EEG recorded after the MP exposure. A subgroup of 17 patients was studied on visual ERP recorded during the MP exposure. Using an adapted "odd-ball" paradigm, each patient was instructed to strike a key whenever rare target stimuli were presented. There were three variants of target stimuli (horizontal stripes in (i) left, (ii) right hemifields or (iii) whole field of the screen). The exposure enhanced the positivity of the ERP endogenous complex solely in response to target stimuli in the right hemifield of the screen ($P < 0.01$). The reaction time was shortened by 20 ms in response to all target stimuli ($P < 0.05$). In conclusion, the electromagnetic field of MP may suppress the excessive sleepiness and improve performance while solving a monotonous cognitive task requiring sustained attention and vigilance.

Jha N, Sarsaiya P, Tomar AK, Pardhiya S, Nirala JP, Chaturvedi PK, Gupta S, Rajamani P. Effects of 700MHz radiofrequency radiation (5G lower band) on the reproductive parameters of female Wistar rats. Reprod Toxicol. 2025 Apr 10:108910.

The advent of 5G technology has raised concerns about its potential biological effects, particularly reproductive health being one key area of focus. This study investigated the impact of 700MHz, a lower 5G frequency band, on the reproductive health of female Wistar rats. The experiment analyzed the effects of short-term and long-term exposure to 700MHz mobile radiation on female Wistar rats. Rats were divided into three groups (control, sham-exposed, and exposed), with sample sizes of n=6 for short-term and n=8 for long-term exposure. For short-term exposure, rats were subjected to 6 hrs of radiation daily for 10 days, while for long-term exposure, rats exposed 4 hrs daily for 60 days. Physiological parameters, including estrous cyclicity, were monitored, and histopathological and biochemical analyses were conducted on harvested ovaries. Comet assay was performed to assess DNA damage. The results indicated no changes in estrous cycles or comet assay parameters in either exposure group. Serological hormone levels, including estradiol and progesterone, remained within normal ranges, but a slight yet significant increase in testosterone levels was observed in exposed groups. Oxidative stress markers revealed elevated malondialdehyde (MDA) levels and significant decreases in superoxide dismutase (SOD), total sulfhydryl content, and ferric reducing antioxidant power (FRAP) in exposed ovaries. Histopathological analysis showed no significant changes in ovarian morphology in short-term exposure but revealed alterations, including cystic follicles and abnormal vasculature, in long-term exposure. These findings suggest that 700MHz radiation may induce oxidative stress and tissue changes in ovarian samples over prolonged exposure.

Jonwal C, Sisodia R, K Saxena VK, Kesari KK. Effect of 2.45 GHz microwave radiation on the fertility pattern in male mice. Gen Physiol Biophys 37(4):453-460, 2018.

A number of studies have reported that male reproductive organs are susceptible to electromagnetic fields (EMFs). The aim of this study was to explore the effects of microwave radiation exposures on 6-8 weeks old male Swiss albino mice. Mice were divided into two groups: group I - sham-exposed (Control), and group II - microwaves-exposed (MWs). Mice were exposed to 2.45 GHz with power density 0.25 mW/cm2 and specific absorbtion rate (SAR) 0.09 W/kg. Exposure was given in Plexiglas cages for 2 h/day for 30 days. Results showed that 2.45 GHz microwave radiation resulted in a significant increase ($p < 0.001$) in catalase (CAT), malondialdehyde (MDA), reactive oxygen species (ROS) and decrease ($p < 0.001$) in the levels of glutathione peroxidase (GPx), testosterone and superoxide dismutase (SOD) ($p < 0.05$). Flow cytometer analysis of blood showed the formation of micronuclei in microwave-exposed group. Histopathological changes were also seen in seminiferous tubules of microwave-exposed group as compared to the sham-exposed group. It is concluded that 2.45 GHz microwave radiation exposure causes oxidative stress in testes and it may lead to detrimental and injurious effects on fertility potential of the male reproductive system of Swiss albino mice.

Jooyan N, Goliaei B, Bigdeli B, Faraji-Dana R, Zamani A, Entezami M, Mortazavi SMJ. Direct and indirect effects of exposure to 900 MHz GSM radiofrequency electromagnetic fields on CHO cell line: Evidence of bystander effect by non-ionizing radiation. Environ Res. 174:176-187, 2019.

Introduction: The rapid rise in global concerns about the adverse health effects of exposure to radiofrequency radiation (RFR) generated by common devices such as mobile phones has prompted scientists to further investigate the biological effects of these environmental exposures. Non-targeted effects (NTEs) are responses which do not need a direct exposure to be expressed and are particularly significant at low energy radiations. Although NTEs of ionizing radiation are well documented, there are scarcely any studies on non-targeted responses such as bystander effect (BE) after exposure to non-ionizing radiation. The main goal of this research is to study possible RFR-induced BE. **Material and methods:** Chinese hamster ovary cells were exposed to 900 MHz GSM RFR at an average specific absorption rate (SAR) of 2 W/kg for 4, 12 and 24 hours (h). To generate a uniformly distributed electromagnetic field and avoid extraneous RF exposures a cavity was desined and used. Cell membrane permeability, cell redox activity, metabolic and mitotic cell death and DNA damages were analyzed. Then the most effective exposure durations and statistically significant altered parameters were chosen to assess the induction of BE through medium transfer procedure. Furthermore, intra and extra cellular reactive oxygen species (ROS) levels were measured to assess the molecular mechanism of BE induced by non-ionizing radiation. **Results:** No statistically significant alteration was found in cell membrane permeability, cell redox activity, metabolic cell activity and micronuclei (MN) frequency in the cells directly exposed to RFR for 4, 12, or 24 h. However, RFR exposure for 24 h caused a statistically significant decrease in clonogenic ability as well as a statistically significant increase in olive moment in both directly exposed and bystander cells which received media from RFR-exposed cells (conditioned culture medium; CCM). Exposure to RFR also statistically significant elevated both intra and extra cellular levels of ROS. **Conclusion:** Our observation clearly indicated the induction of BE in cells treated with CCM. To our knowledge, this is the first report that a non-ionizing radiation (900 MHz GSM RFR) can induce bystander effect. As reported for ionizing radiation, our results proposed that ROS can be a potential molecule in indirect effect of RFR. On the other hand, we found the importance of ROS in direct effect of RFR but in different ways.

Jooyan N, Mortazavi SMJ, Goliaei B, Faraji-Dana R. Indirect effects of interference of two emerging environmental contaminants on cell health: Radiofrequency radiation and gold nanoparticles. Chemosphere 11:140942, 2023.

Background: The global need for wireless technologies is growing rapidly. So, we have been exposed to a new type of environmental pollution: radiofrequency radiation (RFR). Recent studies have shown that RFR can cause not only direct effects but also indirect or non-targeted effects such as the bystander effect (BE). In this study, we investigated the BE induced by RFR in the present of gold nanoparticles (GNP). Moreover, we studied the expression of cyclooxygenase-2 (COX-2). **Methods:** Non-toxic dose of 15-nm GNP was used to treat the Chinese Hamster Ovary (CHO) cells. After 48 h of incubation, cells were exposed to 900 MHz GSM RFR for 24 h. Then we collected the cell culture medium of these cells (conditioned culture medium, CCM) and transferred it to new cells (bystander cells). Cell deaths, DNA breaks, oxidative stress and COX-2 expression were analyzed in all groups. **Results:** The results showed that RFR increased metabolic death in cells treated with GNP. Inversely, the colony formation ability was reduced in bystander cells and RFR exposed cells either in the presence or absence of GNP. Also, the level of reactive oxygen species (ROS) in GNP treated cells showed a

significant reduction compared to those of untreated cells. However, RFR-induced DNA breaks and the frequencies of micronuclei (MN) were not significantly affected by GNP. The expression of COX-2 mRNA increased in RFR GNP treated cells, but the difference was not significant. **Conclusion:** Our results for the first time indicated that RFR induce indirect effects in the presence of GNP. However, the molecular mediators of these effects differ from those in the absence of GNP. Also, to our knowledge, this is the first study to show that COX-2 is not involved in the bystander effect induced by 900 MHz RFR.

Karadayi A, Sarsmaz H, Çigel A, Engiz B, Üna l N, Ürkmez S, Gürgen S.Does Microwave exposure at different doses in the pre/postnatal period affect growing rat bone development? Physiol Res 73(1):157-172, 2024. (sRANKL- involved in bone regeneration and remodeling; OPG-protein involved in regulation of bone density. Increased apoptosis observed.)

Effects of pre/postnatal 2.45 GHz continuous wave (CW), Wireless-Fidelity (Wi-Fi) Microwave (MW) irradiation on bone have yet to be well defined. The present study used biochemical and histological methods to investigate effects on bone formation and resorption in the serum and the tibia bone tissues of growing rats exposed to MW irradiation during the pre/postnatal period. Six groups were created: one control group and five experimental groups subjected to low-level different electromagnetic fields (EMF) of growing male rats born from pregnant rats. During the experiment, the bodies of all five groups were exposed to 2.45 GHz CW-MW for one hour/day. EMF exposure started after fertilization in the experimental group. When the growing male rats were 45 days old in the postnatal period, the control and five experimental groups' growing male and maternal rats were sacrificed, and their tibia tissues were removed. Maternal rats were not included in the study. No differences were observed between the control and five experimental groups in Receptor Activator Nuclear factor-kB (RANK) biochemical results. In contrast, there was a statistically significant increase in soluble Receptor Activator of Nuclear factor-kB Ligand (sRANKL) and Osteoprotegerin (OPG) for 10 V/m and 15 V/m EMF values. Histologically, changes in the same groups supported biochemical results. These results indicate that pre/postnatal exposure to 2.45 GHz EMF at 10 and 15 V/m potentially affects bone development.

Karamazı Y, Emre M, Uçar S, Aksoy G, Emre T, Tokuş M. Effect of 6 GHz radiofrequency electromagnetic field on the development of fetal bones. Electromagn Biol Med 44:17-25, 2025.

This study examined the impact of 6 GHz (0.054 W/kg SAR) Radiofrequency-Electromagnetic Field (RF-EMF) on prenatal bone development. In this study, 20 female and 20 male Wistar Albino rats divided into four groups. The Control group received no treatment, while in Group-I, only male rats were exposed to RF-EMF, female rats had no exposure. Group-II, both male and female rats received RF-EMF treatment. While in Group-III, only female rats were exposed to RF-EMF, male rats had no exposure. The exposure lasted 4 hours per day for 6 weeks. The rats were then allowed to mate within the group. After pregnancy, pregnant rats (Group-II and III) were exposed 4 hours per day for 18 days. On the 18th day of gestation, fetuses were removed and their weight and various lengths were measured. The skeletal system development of fetuses was examined with double skeletal staining method and assessed ossification in the extremities. In the study, fetal weights, head-tail length, occipital-frontal and parietal-parietal lengths

significantly increased in all exposure groups when compared to the control group ($p < 0.001$). Although occipital-frontal length was smallest in Group-I, Group-II and Group-III were more higher than the control group ($p < 0.001$). The bones of the anterior and posterior extremities showed significant increases in length, ossification zone length, and ossification percentage in all experimental groups compared to the control group ($p < 0.001$). Our study showed that rats exposed to 6 GHz (0.054 W/kg) RF-EMF during the prenatal period had significant increases in bone development

Katirci E, Kirimlioglu E, Oflamaz AO, Hidisoglu E, Cernomorcenco A, Yargıcoğlu P, Ozen S, Demir N. Expression levels of tam receptors and ligands in the testes of rats exposed to short and middle-term 2100 MHz radiofrequency radiation. Bioelectromagnetics. 45:235-248, 2024.

With advances in technology, the emission of radiofrequency radiation (RFR) into the environment, particularly from mobile devices, has become a growing concern. Tyro 3, Axl, and Mer (TAM) receptors and their ligands are essential for spermatogenesis and testosterone production. RFR has been shown to induce testicular cell apoptosis by causing inflammation and disrupting homeostasis. This study aimed to investigate the role of TAM receptors and ligands in the maintenance of homeostasis and elimination of apoptotic cells in the testes (weeks), short-term sham exposure (sham/1 week), and middle-term sham exposure (sham/10 weeks). Testicular morphology was assessed using hematoxylin-eosin staining, while immunohistochemical staining was performed to assess expression levels of TAM receptors and ligands in the testes of all groups. The results showed that testicular morphology was normal in the control, sham/1 week, and sham/10 weeks groups. However, abnormal processes of spermatogenesis and seminiferous tubule morphology were observed in RFR exposure groups. Cleaved Caspase 3 immunoreactivity showed statistically significant difference in 1 and 10 weeks exposure groups compared to control group. Moreover, there was no significant difference in the immunoreactivity of Tyro 3, Axl, Mer, Gas 6, and Pros 1 between groups. Moreover, Tyro 3 expression in Sertoli cells was statistically significantly increased in RFR exposure groups compared to the control. Taken together, the results suggest that RFR exposure negatively affects TAM signalling, preventing the clearance of apoptotic cells, and this process may lead to infection and inflammation. As a result, rat testicular morphology and function may be impaired.

Keleş, A.İ., Nyengaard, J.R., Odacı, E. Changes in pyramidal and granular neuron numbers in the rat hippocampus 7 days after exposure to a continuous 900-MHz electromagnetic field during early and mid-adolescence. J Chem Neuroanat. 101:101681, 2019.

The aim of this study was to investigate qualitative and quantitative changes in pyramidal and granule neurons in the male rat hippocampus after exposure to a continuous 900-megahertz (MHz) electromagnetic field (EMF) for 25 days during early and mid-adolescence. Three-week-old (21 day) healthy Sprague Dawley male rats were divided equally into control (CON), pseudo-exposed (PEX) and EMF groups. EMF rats were exposed to a 900-MHz EMF in an EMF-application cage, while the PEX rats were placed in the same cage without being exposed to EMF. No procedure was performed in CON. EMF was applied for 1 h/day, every day for 25 days. Following the 900-MHz EMF and pseudo-exposed applications, behavioral tests were

performed for seven days. Then, all animals were euthanized and their brains were removed. Following histological tissue procedures, sections were taken from tissues and stained with toluidine blue. The optical fractionation technique was performed to estimate the pyramidal neuron numbers in the CA1, CA2-3 and hilus regions of the hippocampus and granule neuron numbers in the dentate gyrus region. Our findings indicated that the number of pyramidal and granule neurons in the hippocampus of the EMF group was statistically higher than PEX. Furthermore, the histopathological results showed that the cytoplasm of pyramidal (in the hilus, CA1, CA2 and CA3 region) and granular (in the dentate gyrus region) cells at the hippocampus were disrupted, as evident by intensive staining around cytoplasm and some artifacts were detected in the EMF group. In addition, statistical comparisons of the mean body weights and brain weights of the study groups revealed no significant differences. There was no statistically significant difference between the PEX and EMF groups in terms of temperature ($p > 0.05$) or humidity ($p > 0.05$) in the cages. In conclusion, higher numbers of both pyramidal and granule neurons were found in the male rat hippocampus after continuous 900-MHz EMF treatment.

Keleş AI, Kaya H, Keleş G, Erol HS, Mercantepe T, Odaci E. Exposure to a 0.9-GHz electromagnetic field on postnatal days 21-45 may trigger the renin-angiotensin system in male rat: a histological and biochemical study. J Mol Histol 56(1):22, 2024.

The aim of this study was to examine the relationship between the renin-angiotensin system (RAS) and histological and biochemical changes occurring in the kidney tissue of male rats exposed to a 0.9 GHz electromagnetic field (EMF). Twelve male rats aged 21 days were randomly assigned to control (C-Gr) and EMF (EMF-Gr) groups. No procedure was performed on C-Gr, while the EMF-Gr rats were exposed to a 0.9 GHz EMF on postnatal days 21-45 (one hour a day for 25 days). Tissues were removed at the end of the experiment and evaluated using biochemical, and histopathological methods. Increased kidney tissue volume and weight and total body weight were determined in the group exposed to EMF. Lipid peroxidation, glutathione, catalase, and superoxide dismutase also increased in the kidney tissue of the EMF-Gr rats. Histopathological evaluation revealed cortical/medullary bleeding/obstruction and widespread fibrosis, dilatation, vacuolization, and degeneration in distal and proximal tubules, decreased and atypical parietal cells, and degeneration in epithelial cells. Additionally, dilated and degenerated glomeruli in the Malpighian body, Bowman's membrane degeneration and degeneration in the vascular pole, podocyte, pedicel and mesangial cells were also observed. As a result of exposure to EMF, oxidative stress, tissue volume and weight increased, and histopathological changes caused the formation of a pathway that triggers RAS in kidney tissues. In conclusion, long-term exposure to 0.9 GHz EMF can activate the renin-angiotensin system in the rat kidney, and we think that such activation may be associated with structural, histopathological, and biochemical changes occurring in renal tissue.

Kerimoğlu G, Aslan A, Baş O, Çolakoğlu S, Odacı E. Adverse effects in lumbar spinal cord morphology and tissue biochemistry in Sprague Dawley male rats following exposure to a continuous 1-h a day 900-MHz electromagnetic field throughout adolescence. J Chem Neuroanat. 78:125-130, 2016a.

Cell phones, an indispensable element of daily life, are today used at almost addictive levels by adolescents. Adolescents are therefore becoming increasingly exposed to the effect of the

electromagnetic field (EMF) emitted by cell phones. The purpose of this study was to investigate the effect of exposure to a 900-MHz EMF throughout adolescence on the lumbar spinal cord using histopathological, immunohistochemical and biochemical techniques. Twenty-four Sprague Dawley (28.3-43.9g) aged 21days were included in the study. These were divided equally into three groups - control (CG), sham (SG) and electromagnetic (ELMAG). No procedure was performed on the CG rats until the end of the study. SG and ELMAG rats were kept inside an EMF cage (EMFC) for 1h a day every day at the same time between postnatal days 22 and 60. During this time, ELMAG rats were exposed to the effect of a 900-MHz EMF, while the SG rats were kept in the EMFC without being exposed to EMF. At the end of the study, the lumbar regions of the spinal cords of all rats in all groups were extracted. Half of each extracted tissue was stored at -80°C for biochemical analysis, while the other half was used for histopathological and immunohistochemical analyses. In terms of histopathology, a lumbar spinal cord with normal morphology was observed in the other groups, while morphological irregularity in gray matter, increased vacuolization and infiltration of white matter into gray matter were pronounced in the ELMAG rats. The cytoplasm of some neurons in the gray matter was shrunken and stained dark, and vacuoles were observed in the cytoplasms. The apoptotic index of glia cells and neurons were significantly higher in ELMAG compared to the other groups. Biochemical analysis revealed a significantly increased MDA value in ELMAG compared to CG, while SOD and GSH levels decreased significantly. In conclusion, our study results suggest that continuous exposure to a 900-MHz EMF for 1h a day through all stages of adolescence can result in impairments at both morphological and biochemical levels in the lumbar region spinal cords of Sprague Dawley rats.

Kerimoğlu G, Hancı H, Baş O, Aslan A, Erol HS, Turgut A, Kaya H, Çankaya S, Sönmez OF, Odacı E. Pernicious effects of long-term, continuous 900-MHz electromagnetic field throughout adolescence on hippocampus morphology, biochemistry and pyramidal neuron numbers in 60-day-old Sprague Dawley male rats. J Chem Neuroanat. 77:169-175, 2016b

The central nervous system (CNS) begins developing in the intrauterine period, a process that continues until adulthood. Contact with chemical substances, drugs or environmental agents such as electromagnetic field (EMF) during adolescence therefore has the potential to disturb the development of the morphological architecture of components of the CNS (such as the hippocampus). The hippocampus is essential to such diverse functions as memory acquisition and integration and spatial maneuvering. EMF can result in severe damage to both the morphology of the hippocampus and its principal functions during adolescence. Although children and adolescents undergo greater exposure to EMF than adults, the information currently available regarding the effects of exposure to EMF during this period is as yet insufficient. This study investigated the 60-day-old male rat hippocampus following exposure to 900 megahertz (MHz) EMF throughout the adolescent period using stereological, histopathological and biochemical analysis techniques. Eighteen male Sprague Dawley rats aged 21days were assigned into control, sham and EMF groups on a random basis. No procedure was performed on the control group rats. The EMF group (EMFGr) was exposed to a 900-MHz EMF for 1h daily from beginning to end of adolescence. The sham group rats were held in the EMF cage but were not exposed to EMF. All rats were sacrificed at 60days of age. Their brains were extracted and halved. The left hemispheres were set aside for biochemical analyses and the right hemispheres were subjected to stereological and histopathological evaluation. Histopathological examination

revealed increased numbers of pyknotic neurons with black or dark blue cytoplasm on EMFGr slides stained with cresyl violet. Stereological analyses revealed fewer pyramidal neurons in EMFGr than in the other two groups. Biochemical analyses showed an increase in malondialdehyde and glutathione levels, but a decrease in catalase levels in EMFGr. Our results indicate that oxidative stress-related morphological damage and pyramidal neuron loss may be observed in the rat hippocampus following exposure to 900-MHz EMF throughout the adolescent period.

Kerimoğlu G, Mercantepe T, Erol HS, Turgut A, Kaya H, Çolakoğlu S, Odacı E. Effects of long-term exposure to 900 megahertz electromagnetic field on heart morphology and biochemistry of male adolescent rats. Biotech Histochem. 91(7):445-454, 2016c.

The pathological effects of exposure to an electromagnetic field (EMF) during adolescence may be greater than those in adulthood. We investigated the effects of exposure to 900 MHz EMF during adolescence on male adult rats. Twenty-four 21-day-old male rats were divided into three equal groups: control (Cont-Gr), sham (Shm-Gr) and EMF-exposed (EMF-Gr). EMF-Gr rats were placed in an EMF exposure cage (Plexiglas cage) for 1 h/day between postnatal days 21 and 59 and exposed to 900 MHz EMF. Shm-Gr rats were placed inside the Plexiglas cage under the same conditions and for the same duration, but were not exposed to EMF. All animals were sacrificed on postnatal day 60 and the hearts were extracted for microscopic and biochemical analyses. Biochemical analysis showed increased levels of malondialdehyde and superoxide dismutase, and reduced glutathione and catalase levels in EMF-Gr compared to Cont-Gr animals. Hematoxylin and eosin stained sections from EMF-Gr animals exhibited structural changes and capillary congestion in the myocardium. The percentage of apoptotic myocardial cells in EMF-Gr was higher than in either Shm-Gr or Cont-Gr animals. Transmission electron microscopy of myocardial cells of EMF-Gr animals showed altered structure of Z bands, decreased myofilaments and pronounced vacuolization. We found that exposure of male rats to 900 MHz EMF for 1 h/day during adolescence caused oxidative stress, which caused structural alteration of male adolescent rat heart tissue.

Kerimoğlu G, Güney C, Ersöz Ş, Odacı E.A histopathological and biochemical evaluation of oxidative injury in the sciatic nerves of male rats exposed to a continuous 900-megahertz electromagnetic field throughout all periods of adolescence. J Chem Neuroanat. 91:1-7, 2018.

The effects on human health of the electromagnetic field (EMF) emitted by mobile phones, used by approximately 7 billion people worldwide, have become an important subject for scientific research. Studies have suggested that the EMF emitted by mobile phones can cause oxidative stress in different tissues and age groups. Young people in adolescence, a time period when risky behaviors and dependences increase, use mobile phones more than adults. The EMF emitted by mobile phones, which are generally carried in the pocket or in bags when not in use, will very probably affect the sciatic nerve. No previous study has investigated the effect of mobile phone use in adolescence on peripheral nerve. This study was planned accordingly. Twenty-four male Sprague Dawley rats aged 21 days were divided equally into control (CGr), Sham (SGr) and EMF (EMFGr) groups. No procedure was performed on CGr rats. EMFGr were exposed to the effect of a 900-megahertz (MHz) EMF for 1 h at the same time every day between postnatal days

21-59 (the entire adolescent period) inside a cage in the EMF apparatus. SGr rats were placed inside the cage for 1 h every day without being exposed to EMF. All rats were sacrificed at the end of the study period, and 1 cm sections of sciatic nerve were extracted. Malondialdehyde (MDA), glutathione, catalase (CAT) superoxide dismutase (SOD) values were investigated biochemically in half of the right sciatic nerve tissues. The other halves of the nerve tissues were subjected to routine histopathological tissue procedures, sectioned and stained with hematoxylin and eosin (H&E) and Masson's trichrome. Histopathological evaluation of slides stained with Masson's trichrome and H&E revealed a normal appearance in Schwann cells and axons in all groups. However, there was marked thickening in the epineurium of sciatic nerves from EMFGr rats. MDA, SOD and CAT levels were higher in EMFGr than in CGr and SGr at biochemical analyses. Apoptotıc index (AI) analysis revealed a significant increase in the number of TUNEL (+) cells when EMFGr was compared with CGr and SGr. In conclusion, our study results suggest that continuous exposure to a 900-MHz EMF for 1 h throughout adolescence can cause oxidative injury and thickening in the epineurium in the sciatic nerve in male rats.

Kesari KK, Behari J. Fifty-gigahertz microwave exposure effect of radiations on rat brain. Appl Biochem Biotechnol (1):126-139, 2009.

The object of this study is to investigate the effects of 50-GHz microwave radiation on the brain of Wistar rats. Male rats of the Wistar strain were used in the study. Animals of 60-day age were divided into two groups-group 1, sham-exposed, and group 2, experimental (microwave-exposed). The rats were housed in a temperature-controlled room (25 degrees C) with constant humidity (40-50%) and received food and water ad libitum. During exposure, rats were placed in Plexiglas cages with drilled ventilation holes and kept in an anechoic chamber. The animals were exposed for 2 h a day for 45 days continuously at a power level of 0.86 microW/cm(2) with nominal specific absorption rate 8.0 x 10(-4) w/kg. After the exposure period, the rats were killed and homogenized, and protein kinase C (PKC), DNA double-strand break, and antioxidant enzyme activity [superoxides dismutase (SOD), catalase, and glutathione peroxidase (GPx)] were estimated in the whole brain. Result shows that the chronic exposure to these radiations causes DNA double-strand break (head and tail length, intensity and tail migration) and a significant decrease in GPx and SOD activity ($p = or<0.05$) in brain cells, whereas catalase activity shows significant increase in the exposed group of brain samples as compared with control ($p = or<0.001$). In addition to these, PKC decreased significantly in whole brain and hippocampus ($p < 0.05$). All data are expressed as mean +/- standard deviation. We conclude that these radiations can have a significant effect on the whole brain.

Kesari KK, Behari J. Microwave exposure affecting reproductive system in male rats. Appl Biochem Biotechnol 31:495-498, 2010a.

The object of present study is to investigate the effects of 50 GHz microwave frequency electromagnetic fields on reproductive system of male rats. Male rats of Wistar strain were used in the study. Animals 60 days old were divided into two groups-group I sham exposed and group II experimental (microwave exposed). During exposure, rats were confined in Plexiglas cages with drilled ventilation holes for 2 h a day for 45 days continuously at a specified specific absorption rate of 8.0 x 10(-4) W/kg. After the last exposure, the rats were sacrificed

immediately and sperms were collected. Antioxidant enzyme (superoxide dismutase (SOD), glutathione peroxidase (GPx), and catalase), histone kinase, apoptosis, and cell cycle were analyzed in sperm cells. Result shows a significant decrease in the level of sperm GPx and SOD activity ($p </= 0.05$), whereas catalase shows significant increase in exposed group of sperm samples as compared with control ($p < 0.02$). We observed a statistically significant decrease in mean activity of histone kinase as compared to the control ($p < 0.016$). The percentage of cells dividing in a spermatogenesis was estimated by analyzing DNA per cell by flow cytometry. The percentage of apoptosis in electromagnetic field exposed group shows increased ratio as compared to sham exposed ($p < 0.004$). There were no significant differences in the G(0)/G phase; however, a significant decrease ($p < 0.026$) in S phase was obtained. Results also indicate a decrease in percentage of G/M transition phase of cell cycle in exposed group as compared to sham exposed ($p < 0.019$). We conclude that these radiations may have a significant effect on reproductive system of male rats, which may be an indication of male infertility.

Kesari K.K. and Behari J. Effects of microwave at 2.45 GHz radiations on reproductive system of male rats. Toxicology Environmental Chemistry 92(6):1135-1147, 2010b

Radio frequency and microwave radiations are a part of non-ionizing electromagnetic radiations present in the environment and are now being perceived as health risks. The present study was performed to investigate the effect of 2.45 GHz microwave radiation on reproductive pattern of male Wistar rats. Animals were exposed at 2.45 GHz frequency with 0.34 mW cm^{-2} power density continuously for 2 h day^{-1} for 35 days, where the whole body specific absorption rate was 0.11 W kg^{-1}. Exposure occurred in a ventilated plexiglass cage and kept in anechoic chamber at a distance of 2 m from the horn antenna. In the present study, apoptosis was tested using terminal deoxynucleotide transferase dUTP nick end labeling assay. Normal and apoptotic sperm cells were also quantified by flow cytometry. Antioxidant enzymes (superoxide dismutase (SOD), glutathione peroxidase (GPx), and catalase (CAT)) were also determined to confirm any mutagenic effects, such as DNA fragmentation. Chronic exposure to these radiations produced formation of apoptotic cells in testis. In addition, a significant decrease in the levels of GPx, and SOD activities as well as an increase in CAT activity was observed in the exposed group. These results indicate that a low level exposure of microwave radiations exerts a negative impact on male reproductive system function.

Kesari, K.K., Behari, J., Kumar, S. Mutagenic response of 2.45 GHz radiation exposure on rat brain. Int J Radiat Biol. 86:334-343, 2010.

Purpose: To investigate the effect of 2.45 GHz microwave radiation on rat brain of male wistar strain.**Material and methods:** Male rats of wistar strain (35 days old with 130 +/- 10 g body weight) were selected for this study. Animals were divided into two groups: Sham exposed and experimental. Animals were exposed for 2 h a day for 35 days to 2.45 GHz frequency at 0.34 mW/cm(2) power density. The whole body specific absorption rate (SAR) was estimated to be 0.11 W/Kg. Exposure took place in a ventilated Plexiglas cage and kept in anechoic chamber in a far field configuration from the horn antenna. After the completion of exposure period, rats were sacrificed and the whole brain tissue was dissected and used for study of double strand DNA (Deoxyribonucleic acid) breaks by micro gel electrophoresis and the statistical analysis was

carried out using comet assay (IV-2 version software). Thereafter, antioxidant enzymes and histone kinase estimation was also performed. **Results:** A significant increase was observed in comet head ($P < 0.002$), tail length ($P < 0.0002$) and in tail movement ($P < 0.0001$) in exposed brain cells. An analysis of antioxidant enzymes glutathione peroxidase ($P < 0.005$), and superoxide dismutase ($P < 0.006$) showed a decrease while an increase in catalase ($P < 0.006$) was observed. A significant decrease ($P < 0.023$) in histone kinase was also recorded in the exposed group as compared to the control (sham-exposed) ones. One-way analysis of variance (ANOVA) method was adopted for statistical analysis. **Conclusion:** The study concludes that the chronic exposure to these radiations may cause significant damage to brain, which may be an indication of possible tumour promotion (Behari and Paulraj 2007).

Kesari KK, Meena R, Nirala J, Kumar J, Verma HN. Effect of 3G cell phone exposure with computer controlled 2-D stepper motor on non-thermal activation of the hsp27/p38MAPK stress pathway in rat brain. Cell Biochem Biophys. 68(2):347-358, 2014.

Cell phone radiation exposure and its biological interaction is the present concern of debate. Present study aimed to investigate the effect of 3G cell phone exposure with computer controlled 2-D stepper motor on 45-day-old male Wistar rat brain. Animals were exposed for 2 h a day for 60 days by using mobile phone with angular movement up to zero to 30°. The variation of the motor is restricted to 90° with respect to the horizontal plane, moving at a pre-determined rate of 2° per minute. Immediately after 60 days of exposure, animals were scarified and numbers of parameters (DNA double-strand break, micronuclei, caspase 3, apoptosis, DNA fragmentation, expression of stress-responsive genes) were performed. Result shows that microwave radiation emitted from 3G mobile phone significantly induced DNA strand breaks in brain. Meanwhile a significant increase in micronuclei, caspase 3 and apoptosis were also observed in exposed group ($P < 0.05$). Western blotting result shows that 3G mobile phone exposure causes a transient increase in phosphorylation of hsp27, hsp70, and p38 mitogen-activated protein kinase (p38MAPK), which leads to mitochondrial dysfunction-mediated cytochrome c release and subsequent activation of caspases, involved in the process of radiation-induced apoptotic cell death. Study shows that the oxidative stress is the main factor which activates a variety of cellular signal transduction pathways, among them the hsp27/p38MAPK is the pathway of principle stress response. Results conclude that 3G mobile phone radiations affect the brain function and cause several neurological disorders.

Kues HA, Monahan JC, D'Anna SA, McLeod DS, Lutty GA, Koslov S, Increased sensitivity of the non-human primate eye to microwave radiation following ophthalmic drug pretreatment. Bioelectromagnetics 13(5):379-393, 1992.

Previous studies in our laboratory have established that pulsed microwaves at 2.45 GHz and 10 mW/cm2 are associated with production of corneal endothelial lesions and with disruption of the blood-aqueous barrier in the non-human primate eye. In the study reported here we examined ocular damage in monkeys (M. mulatta and M. fascicularis) following topical treatment with one of two ophthalmic drugs (timolol maleate and pilocarpine) that preceded exposure to pulsed microwaves. Anesthetized monkeys were sham exposed or exposed to pulsed, 2.45 GHz microwaves (10 microseconds, 100 pps) at average power densities of 0.2, 1, 5, 10, or 15 mW/cm2 4 h a day for 3 consecutive days (respective SARs were 0.052, 0.26, 1.3, 2.6, and 3.9 W/kg). Immediately before microwave exposure, one or both eyes were treated topically with

one drop of 0.5% timolol maleate or of 2% pilocarpine. Following administration of a drug, we observed a significant reduction in the power-density threshold (from 10 to 1 mW/cm2) for induction of corneal endothelial lesions and for increased vascular permeability of the iris. Diagnostic procedures (in vivo specular microscopy and fluorescein iris angiography) were performed following each exposure protocol. In addition, increased vascular permeability was confirmed with horseradish peroxidase tracer techniques. Although we did not measure intraocular temperatures in experimental animals, the results suggest that a mechanism other than significant heating of the eye is involved. Our data indicate that pulsed microwaves at an average SAR of 0.26 W/kg, if administered after pretreatment with ophthalmic drugs, can produce significant ocular effects in the anesthetized primate.

Kulaber A, Kerimoğlu G, Ersöz Ş, Çolakoğlu S, Odacı E. Alterations of thymic morphology and antioxidant biomarkers in 60-day-old male rats following exposure to a continuous 900 MHz electromagnetic field during adolescence. Biotech Histochem. 92(5):331-337, 2017.

We investigated changes in thymic tissue of male rats exposed to a 900 megahertz (MHz) electromagnetic field (EMF) on postnatal days 22-59. Three groups of six 21-day-old male Sprague-Dawley rats were allocated as: control (CG), sham (SG) and EMF (EMFG) groups. No procedure was performed on the CG rats. SG rats were placed in a Plexiglas cage for 1 h every day between postnatal days 22 and 59 without exposure to EMF. EMFG rats were placed in the same cage for the same periods as the SG rats and were exposed to 900 MHz EMF. Rats were sacrificed on postnatal day 60. Sections of thymus were stained for histological assessment. Oxidant/antioxidant parameters were investigated biochemically. Malondialdehyde (MDA) levels in EMFG increased compared to the other groups. Extravascular erythrocytes were observed in the medullary/corticomedullary regions in EMFG sections. We found that 900 MHz EMF applied for 1 h/day on postnatal days 22-59 can increase tissue MDA and histopathological changes in male rat thymic tissue.

Kumar, S., Kesari, K.K., Behari, J. Influence of microwave exposure on fertility of male rats. Fertil Steril. 95:1500-1502, 2010a.

The present study investigates the effect of 10-GHz microwave radiation on the fertility pattern of 70-day-old male rats (sham exposed and exposed), which were exposed for 2 h/d for 45 days continuously at a specific absorption rate of 0.014 W/kg and a power density of 0.21 mW/cm(2). Results show a significant change in the level of reactive oxygen species, histone kinase, apoptotic cells, and percentage of G(2)/M transition phase of cell cycle in the exposed group compared with the sham-exposed group. The study concludes that there is a significant effect of microwave radiations on the reproductive pattern in male rats, which is a causative factor of male infertility.

Kumar, S., Kesari, K.K., Behari, J.. Evaluation of genotoxic effects in male Wistar rats following microwave exposure. Indian J Exp Biol. 48:586-592, 2010b.

Wistar rats (70 days old) were exposed for 2 h a day for 45 days continuously at 10 GHz [power density 0.214 mW/cm2, specific absorption rate (SAR) 0.014 W/kg] and 50 GHz (power density 0.86 microW/cm2, SAR 8.0 x10(-4) W/kg). Micronuclei (MN), reactive oxygen species (ROS), and antioxidant enzymes activity were estimated in the blood cells and serum. These radiations

induce micronuclei formation and significant increase in ROS production. Significant changes in the level of serum glutathione peroxidase, superoxide dismutase and catalase were observed in exposed group as compared with control group. It is concluded that microwave exposure can be affective at genetic level. This may be an indication of tumor promotion, which comes through the overproduction of reactive oxygen species.

Kumar S, Kesari KK, Behari J. The therapeutic effect of a pulsed electromagnetic field on the reproductive patterns of male Wistar rats exposed to a 2.45-GHz microwave field. Clinics (Sao Paulo). 66(7):1237-1245, 2011a.

INTRODUCTION: Environmental exposure to man-made electromagnetic fields has been steadily increasing with the growing demand for electronic items that are operational at various frequencies. Testicular function is particularly susceptible to radiation emitted by electromagnetic fields. OBJECTIVES: This study aimed to examine the therapeutic effects of a pulsed electromagnetic field (100 Hz) on the reproductive systems of male Wistar rats (70 days old). METHODS: The experiments were divided into five groups: microwave sham, microwave exposure (2.45 GHz), pulsed electromagnetic field sham, pulsed electromagnetic field (100 Hz) exposure, and microwave/pulsed electromagnetic field exposure. The animals were exposed for 2 hours/day for 60 days. After exposure, the animals were sacrificed, their sperm was used for creatine and caspase assays, and their serum was used for melatonin and testosterone assays. RESULTS: The results showed significant increases in caspase and creatine kinase and significant decreases in testosterone and melatonin in the exposed groups. This finding emphasizes that reactive oxygen species (a potential inducer of cancer) are the primary cause of DNA damage. However, pulsed electromagnetic field exposure relieves the effect of microwave exposure by inducing Faraday currents. CONCLUSIONS: Electromagnetic fields are recognized as hazards that affect testicular function by generating reactive oxygen species and reduce the bioavailability of androgen to maturing spermatozoa. Thus, microwave exposure adversely affects male fertility, whereas pulsed electromagnetic field therapy is a non-invasive, simple technique that can be used as a scavenger agent to combat oxidative stress.

Kumar S, Kesari KK, Behari J. Influence of microwave exposure on fertility of male rats. Fertil Steril. 95(4):1500-1502, 2011b.

The present study investigates the effect of 10-GHz microwave radiation on the fertility pattern of 70-day-old male rats (sham exposed and exposed), which were exposed for 2 h/d for 45 days continuously at a specific absorption rate of 0.014 W/kg and a power density of 0.21 mW/cm(2). Results show a significant change in the level of reactive oxygen species, histone kinase, apoptotic cells, and percentage of G(2)/M transition phase of cell cycle in the exposed group compared with the sham-exposed group. The study concludes that there is a significant effect of microwave radiations on the reproductive pattern in male rats, which is a causative factor of male infertility.

Kumar S, Behari J, Sisodia R. Impact of microwave at X-band in the aetiology of male infertility. Electromagn Biol Med. 31(3):223-232, 2012.

Reports of declining male fertility have renewed interest in assessing the role of environmental and occupational exposures to electromagnetic fields (EMFs) in the aetiology of human infertility. Testicular functions are particularly susceptible to electromagnetic fields. The aim of the present work was to investigate the effect of 10-GHz EMF on male albino rat's reproductive system and to investigate the possible causative factor for such effect of exposure. The study was carried out in two groups of 70-day old adult male albino rats: a sham-exposed and a 10-GHz-exposed group (2 h a day for 45 days). Immediately after completion of the exposure, animals were sacrificed and sperms were extracted from the cauda and caput part of testis for the analysis of MDA, melatonin, and creatine kinase. Creatine kinase results revealed an increased level of phosphorylation that converts creatine to creatine phosphate in sperms after EMF exposure. EMF exposure also reduced the level of melatonin and MDA. It is concluded that microwave exposure could adversely affect male fertility by reducing availability of the above parameters. These results are indications of deleterious effects of these radiations on reproductive pattern of male rats.

Kumar, S., Behari, J., Sisodia, R. Influence of electromagnetic fields on reproductive system of male rats. Int J Radiat Biol. 89:147-154, 2013.

Purpose: Reports of declining male fertility have renewed interest in the role of environmental and occupational exposures in the etiology of human infertility. The aim of the present work was to investigate the effect of 10 GHz exposure on the male Wistar rat's reproductive system and to find out the possible causative factors. **Materials and methods:** The study was divided into sham-exposed and exposed groups. Seventy day-old rats were exposed to 10 GHz microwave radiation for 2 h per day for 45 days at power density 0.21 mW/cm(2) and specific absorption rate (SAR) of 0.014 W/kg. After the end of the experiment, blood samples were collected for the estimation of in vivo chromosomal aberration damage and micronucleus test. Spermatozoa were taken out for estimation of Caspase-3, comet assay, testosterone and electron microscopy and compared with sham-exposed. **Results:** The study of scanning electron microscopic revealed shrinkage of the lumen of the seminiferous tubules. Apoptotic bodies were found in exposed group. A flow cytometry examination showed formation of micronuclei body in lymphocytes of exposed group. Comet assay confirmed DNA (deoxyribonucleic acid) strand break. Testosterone level was found significantly decreased with the shrinkage of testicular size. **Conclusions:** 10 GHz field has an injurious effect on fertility potential of male-exposed animals.

Kumar, A, Singh H.P., Batish, D.R., Kaur, S., Kohli, R.K. EMF radiations (1800 MHz)-inhibited early seedling growth of maize (Zea mays) involves alterations in starch and sucrose metabolism. Protoplasma. 253:1043-1049, 2016.

The present study investigated the impact of 1800-MHz electromagnetic field radiations (EMF-r), widely used in mobile communication, on the growth and activity of starch-, sucrose-, and phosphate-hydrolyzing enzymes in Zea mays seedlings. We exposed Z. mays to modulated continuous wave homogenous EMF-r at specific absorption rate (SAR) of 1.69±0.0 × 10(-1) W kg(-1) for ½, 1, 2, and 4 h. The analysis of seedlings after 7 days revealed that short-term exposure did not induce any significant change, while longer exposure of 4 h caused significant growth and biochemical alterations. There was a reduction in the root and coleoptile length with more pronounced effect on coleoptile growth (23 % reduction on 4-h exposure). The contents of

photosynthetic pigments and total carbohydrates declined by 13 and 18 %, respectively, in 4-h exposure treatments compared to unexposed control. The activity of starch-hydrolyzing enzymes-α- and β-amylases-increased by ∼92 and 94 %, respectively, at an exposure duration of 4 h, over that in the control. In response to 4-h exposure treatment, the activity of sucrolytic enzymes-acid invertases and alkaline invertases-was increased by 88 and 266 %, whereas the specific activities of phosphohydrolytic enzymes (acid phosphatases and alkaline phosphatases) showed initial increase up to ≤2 h duration and then declined at >2 h exposure duration. The study concludes that EMF-r-inhibited seedling growth of Z. mays involves interference with starch and sucrose metabolism.

Kumar, A., Kaur, S., Chandel, S., Singh, H.P., Batish, D.R., Kohli, R.K. Comparative cyto- and genotoxicity of 900 MHz and 1800 MHz electromagnetic field radiations in root meristems of Allium cepa. Ecotoxicol Environ Saf. 188:109786, 2020.

In the last few decades, tremendous increase in the use of wireless electronic gadgets, particularly the cell phones, has significantly enhanced the levels of electromagnetic field radiations (EMF-r) in the environment. Therefore, it is pertinent to study the effect of these radiations on biological systems including plants. We investigated comparative cytotoxic and DNA damaging effects of 900 and 1800 MHz EMF-r in Allium cepa (onion) root meristematic cells in terms of mitotic index (MI), chromosomal aberrations (CAs) and single cell gel electrophoresis (comet assay). Onion bulbs were subjected to 900 and 1800 MHz (at power densities 261 ± 8.50 mW m^{-2} and 332 ± 10.36 mW m^{-2}, respectively) of EMF-r for 0.5 h, 1 h, 2 h, and 4 h. Root length declined by 13.2% and 12.3%, whereas root thickness was increased by 46.7% and 48.3% after 4 h exposure to 900 MHz and 1800 MHz, respectively. Cytogenetic studies exhibited clastogenic effect of EMF-r as depicted by increased CAs and MI. MI increased by 36% and 53% after 2 and 4 h exposure to 900 MHz EMF-r, whereas it increased by 41% and 67% in response to 1800 MHz EMF-r. Aberration index was increased by 41%-266% and 14%-257% during 0.5-4 h of exposure to 900 MHz and 1800 MHz, respectively, over the control. EMF-r exposure decreased % head DNA (DNAH) and increased % tail DNA (DNAT) and olive tail moment (OTM) at both 900 and 1800 EMF-r. In 4 h exposure treatments, head DNA (%) declined by 19% and 23% at 900 MHz and 1800 MHz, respectively. DNAT and OTM were increased by 2.3 and 3.7 fold upon exposure to 900 MHz EMF-r over that in the control, whereas 2.8 and 5.8 fold increase was observed in response to 1800 MHz EMF-r exposure for 4 h and the difference was statistically significant. The study concludes that EMF-r in the communication range (900 and 1800 MHz) adversely affect root meristems in plants and induce cytotoxic and DNA damage. EMF-r induced DNA damage was more pronounced at 1800 MHz than that at 900 MHz.

Kumar, R., Deshmukh, P.S., Sharma, S., Banerjee, B.D. Effect of mobile phone signal radiation on epigenetic modulation in the hippocampus of Wistar rat. Environ Res. 192:110297, 2021.

Exponential increase in mobile phone uses, given rise to public concern regarding the alleged deleterious health hazards as a consequence of prolonged exposure. In 2018, the U.S. National toxicology program reported, two year toxicological studies for potential health hazards from exposure to cell phone radiations. Epigenetic modulations play a critical regulatory role in many

cellular functions and pathological conditions. In this study, we assessed the dose-dependent and frequency-dependent epigenetic modulation (DNA and Histone methylation) in the hippocampus of Wistar rats. A Total of 96 male Wistar rats were segregated into 12 groups exposed to 900 MHz, 1800 MHz and 2450 MHz RF-MW at a specific absorption rate (SAR) of 5.84×10^{-4} W/kg, 5.94×10^{-4} W/kg and 6.4×10^{-4} W/kg respectively for 2 h per day for 1-month, 3-month and 6-month periods. At the end of the exposure duration, animals were sacrificed to collect the hippocampus. Global hippocampal DNA methylation and histone methylation were estimated by ELISA. However, DNA methylating enzymes, DNA methyltransferase1 (DNMT1) and histone methylating enzymes euchromatic histone methylthransferase1 (EHMT1) expression was evaluated by real-time PCR, as well as further validated with Western blot. Alteration in epigenetic modulation was observed in the hippocampus. Global DNA methylation was decreased and histone methylation was increased in the hippocampus. We observed that microwave exposure led to significant epigenetic modulations in the hippocampus with increasing frequency and duration of exposure. Microwave exposure with increasing frequency and exposure duration brings significant ($p < 0.05$) epigenetic modulations which alters gene expression in the hippocampus.

Kunjilwar KK, Behari J Effect of amplitude-modulated radio frequency radiation on cholinergic system of developing rats. Brain Res 601(1-2):321-324, 1993.

We examined the effect of long-term exposure to radio frequency radiation 147 MHz and its sub-harmonics 73.5 and 36.75 MHz amplitude modulated at 16 and 76 Hz (30-35 days, 3 h per day) on cholinergic systems in developing rat brain. A significant decrease in acetylcholine esterase activity was found in exposed rats as compared to the control. Decrease in acetylcholine esterase (AChE) activity was independent of carrier wave frequencies. A short-term exposure did not have any significant effect on AChE activity.

Kuybulu AE, Öktem F, Çiriş İM, Sutcu R, Örmeci AR, Çömlekçi S, Uz E.
Effects of long-term pre- and post-natal exposure to 2.45 GHz wireless devices on developing male rat kidney. Ren Fail. 38(4):571-580, 2016.

Purpose The aim of the present study was to investigate oxidative stress and apoptosis in kidney tissues of male Wistar rats that pre- and postnatally exposed to wireless electromagnetic field (EMF) with an internet frequency of 2.45 GHz for a long time. Methods The study was conducted in three groups of rats which were pre-natal, post-natal. and sham exposed groups. Oxidative stress markers and histological evaluation of kidney tissues were studied. Results Renal tissue malondialdehyde (MDA) and total oxidant (TOS) levels of pre-natal group were high and total antioxidant (TAS) and superoxide dismutase (SOD) levels were low. Spot urine NAG/creatinine ratio was significantly higher in pre- and post-natal groups ($p < 0.001$). Tubular injury was detected in most of the specimens in post-natal groups. Immunohistochemical analysis showed low-intensity staining with Bax in cortex, high-intensity staining with Bcl-2 in cortical and medullar areas of pre-natal group (p values, 0.000, 0.002, 0.000, respectively) when compared with sham group. Bcl2/Bax staining intensity ratios of medullar and cortical area was higher in pre-natal group than sham group ($p = 0.018$, $p = 0.011$). Conclusion Based on this study, it is thought that chronic pre- and post-natal period exposure to wireless internet frequency

of EMF may cause chronic kidney damages; staying away from EMF source in especially pregnancy and early childhood period may reduce negative effects of exposure on kidney.

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

With the development of technology, people are increasingly under the exposure of electromagnetic fields. Individuals with chronic diseases such as diabetes are now long-term exposed to Radio Frequency-RF radiation and extremely low frequency (ELF) magnetic fields (MFs). The purpose of this present study is to investigate oxidative effects and antioxidant parameters of ELF MFs and RF radiation on testis tissue in diabetic and healthy rats. Wistar male rats were divided into 10 groups. Intraperitoneal single dose STZ (65 mg/kg) dissolved in citrate buffer (0.1M (pH 4.5)) was injected to diabetes groups. ELF MFs and RF radiation were used as an electromagnetic exposure for 20 min/day, 5 days/week for one month. Testis tissue oxidant malondialdehyde (MDA), and antioxidants glutathione (GSH), and total nitric oxide (NOx) levels were determined. The results of ANOVA and Mann-Whitney tests were compared; $p < 0.05$ was considered significant. ELF and RF radiation resulted in an increase in testicular tissue MDA and NOX levels ($p < 0.05$), and caused a decrease in GSH levels ($p < 0.05$) in both healthy and diabetic rats, yet more distinctively in diabetic rats. The most pronounced effect was recorded in D-RF + ELF group ($p < 0.005$). Both radiation practices increased the oxidative stress in testis tissue while causing a decrease in antioxidant level which was more distinctive in diabetic rats (Tab. 1, Fig. 3, Ref. 30).

Kwee, S., Raskmark, P., Velizarov, P. Changes in cellular proteins due to environmental non-ionizing radiation. 1. heat-shock proteins. Electro- and Magnetobiol. 20:141-152, 2001.

This paper describes the effect of weak microwave fields on the amounts of heat-shock proteins in cell cultures at various temperatures. The field was generated by signal simulation of the Global System for Mobile communications (GSM) of 960 Mhz, used in portable phones. Transformed human epithelial amnion (AMA) cells, growing on glass coverslips, were exposed in a transverse electromagnetic (TEM) cell to a microwave field, generating a specific absorption rate (SAR) of 2.1 $mW.kg^{-1}$ in the cells. Exposure temperatures were 35, 37, and 40 ± 0.1°C, respectively, and the exposure time was 20 min. The heat-shock proteins Hsp-70 and Hsp-27 were detected by immuno-fluorescence. Higher amounts of Hsp-70 were present in the cells exposed at 35 and 37°C than in the sham-exposed cells. These effects can be considered to be athermal, since the field strength was much lower than the safety standard for absence of heat generation by microwave fields.

(E) Lameth J, Royer J, Martin A, Marie C, Arnaud-Cormos D, Lévêque P, Poirier R, Edeline JM, Mallat M. Repeated Head Exposures to a 5G-3.5 GHz Signal Do Not Alter Behavior but Modify Intracortical Gene Expression in Adult Male Mice. Int J Mol Sci. 26(6):2459,2025. **(AS, LI, CE, GE)**

The fifth generation (5G) of mobile communications promotes human exposure to electromagnetic fields exploiting the 3.5 GHz frequency band. We analyzed behaviors, cognitive functions, and gene expression in mice submitted to asymmetrical head exposure to a 5G-modulated 3.5 GHz signal. The exposures were applied for 1 h daily, 5 days per week over a six-week period, at a specific absorption rate (SAR) averaging 0.19 W/kg over the brain. Locomotor activities in an open field, object location, and object recognition memories were assessed repeatedly after four weeks of exposure and did not reveal any significant effect on the locomotion/exploration, anxiety level, or memory processes. mRNA profiling was performed at the end of the exposure period in two symmetrical areas of the right and left cerebral cortex, in which the SAR values were 0.43 and 0.14 W/kg, respectively. We found significant changes in the expression of less than 1% of the expressed genes, with over-representations of genes related to glutamatergic synapses. The right cortical area differed from the left one by an over-representation of responsive genes encoded by the mitochondrial genome. Our data show that repeated head exposures to a 5G-3.5 GHz signal can trigger mild transcriptome alterations without changes in memory capacities or emotional state.

Lerchl, A., Krüger, H., Niehaus, M., Streckert, J.R., Bitz, A.K., Hansen, V. Effects of mobile phone electromagnetic fields at nonthermal SAR values on melatonin and body weight of Djungarian hamsters (Phodopus sungorus). J Pineal Res. 44:267-272, 2008.

In three experiments, adult male Djungarian hamsters (Phodopus sungorus) were exposed 24 hr/day for 60 days to radio frequency electromagnetic fields (RF-EMF) at 383, 900, and 1800 MHz, modulated according to the TETRA (383 MHz) and GSM standards (900 and 1800 MHz), respectively. A radial waveguide system ensured a well defined and uniform exposure at whole-body averaged specific absorption rates of 80 mW/kg, which is equal to the upper limit of whole-body exposure of the general population in Germany and other countries. For each experiment, using two identical waveguides, hamsters were exposed (n = 120) and sham-exposed (n = 120) in a blind fashion. In all experiments, pineal and serum melatonin levels as well as the weights of testes, brain, kidneys, and liver were not affected. At 383 MHz, exposure resulted in a significant transient increase in body weight up to 4%, while at 900 MHz this body weight increase was more pronounced (up to 6%) and not transient. At 1800 MHz, no effect on body weight was seen. The results corroborate earlier findings which have shown no effects of RF-EMF on melatonin levels in vivo and in vitro. The data are in accordance with the hypothesis that absorbed RF energy may result in metabolic changes which eventually cause body weight increases in exposed animals. The data support the notion that metabolic effects of RF-EMFs need to be investigated in more detail in future studies.

Lian, H.Y., Lin, K.W., Yang, C., Cai, P. Generation and propagation of yeast prion [URE3] are elevated under electromagnetic field. Cell Stress. Cell Stress Chaperones. 23:581-594, 2018.

In this study, we studied the effect of 2.0 GHz radio frequency electromagnetic field (RF-EMF) and 50 Hz extremely low frequency electromagnetic field (ELF-EMF) exposure on prion generation and propagation using two budding yeast strains, NT64C and SB34, as model organisms. Under exposure to RF-EMF or ELF-EMF, the de novo generation and propagation of

yeast prions [URE3] were elevated in both strains. The elevation increased over time, and the effects of ELF-EMF occurred in a dose-dependent manner. The transcription and expression levels of the molecular chaperones Hsp104, Hsp70-Ssa1/2, and Hsp40-Ydj1 were not statistically significantly changed after exposure. Furthermore, the levels of ROS, as well as the activities of superoxide dismutase (SOD) and catalase (CAT), were significantly elevated after short-term, but not long-term exposure. This work demonstrated for the first time that EMF exposure could elevate the de novo generation and propagation of yeast prions and supports the hypothesis that ROS may play a role in the effects of EMF on protein misfolding. The effects of EMF on protein folding and ROS levels may mediate the broad effects of EMF on cell function.

Lin KW, Yang CJ, Lian HY, Cai P. Exposure of ELF-EMF and RF-EMF increase the rate of glucose transport and TCA cycle in budding yeast. Front Microbiol. 7:1378, 2016.

In this study, we investigated the transcriptional response to 50 Hz extremely low frequency electromagnetic field (ELF-EMF) and 2.0 GHz radio frequency electromagnetic field (RF-EMF) exposure by Illumina sequencing technology using budding yeast as the model organism. The transcription levels of 28 genes were upregulated and those of four genes were downregulated under ELF-EMF exposure, while the transcription levels of 29 genes were upregulated and those of 24 genes were downregulated under RF-EMF exposure. After validation by reverse transcription quantitative polymerase chain reaction (RT-qPCR), a concordant direction of change both in differential gene expression (DGE) and RT-qPCR was demonstrated for nine genes under ELF-EMF exposure and for 10 genes under RF-EMF exposure. The RT-qPCR results revealed that ELF-EMF and RF-EMF exposure can upregulate the expression of genes involved in glucose transportation and the tricarboxylic acid (TCA) cycle, but not the glycolysis pathway. Energy metabolism is closely related with the cell response to environmental stress including EMF exposure. Our findings may throw light on the mechanism underlying the biological effects of EMF.

López-Furelos, A., Leiro-Vidal, J.M., Salas-Sánchez, A.Á., Ares-Pena, F.J., López-Martín, M.E. Evidence of cellular stress and caspase-3 resulting from a combined two-frequency signal in the cerebrum and cerebellum of sprague-dawley rats. Oncotarget. 7:64674-64689, 2016.

Multiple simultaneous exposures to electromagnetic signals induced adjustments in mammal nervous systems. In this study, we investigated the non-thermal SAR (Specific Absorption Rate) in the cerebral or cerebellar hemispheres of rats exposed in vivo to combined electromagnetic field (EMF) signals at 900 and 2450 MHz.Forty rats divided into four groups of 10 were individually exposed or not exposed to radiation in a GTEM chamber for one or two hours. After radiation, we used the Chemiluminescent Enzyme-Linked Immunosorbent Assay (ChELISA) technique to measure cellular stress levels, indicated by the presence of heat shock proteins (HSP) 90 and 70, as well as caspase-3-dependent pre-apoptotic activity in left and right cerebral and cerebellar hemispheres of Sprague Dawley rats.Twenty-four hours after exposure to combined or single radiation, significant differences were evident in HSP 90 and 70 but not in caspase 3 levels between the hemispheres of the cerebral cortex at high SAR levels. In the cerebellar hemispheres, groups exposed to a single radiofrequency (RF) and high SAR showed significant differences in HSP 90, 70 and caspase-3 levels compared to control animals. The

absorbed energy and/or biological effects of combined signals were not additive, suggesting that multiple signals act on nervous tissue by a different mechanism.

López-Furelos A, Salas-Sánchez AA, Ares-Pena FJ, Leiro-Vidal JM, López-Martín E. Exposure to radiation from single or combined radio frequencies provokes macrophage dysfunction in the RAW 264.7 cell line. Int J Radiat Biol. (6):607-618, 2018.

PURPOSE: The aim of this study was to determine whether exposure to radiation from single or multiple radio-frequency (RF) signals at 900 and 2450 MHz would induce effects in the RAW 264.7 cell line. MATERIALS AND METHODS: Cell cultures were exposed to single or combined RF for 4, 24, 48, or 72 h in a GTEM electromagnetic test chamber. At the end of the radiation exposure time, viability and cell growth were analyzed by flow cytometry, nitric oxide (NO) production was measured by colorimetry, the expression of HSP70 and TNF-α was ascertained by qPCR, and the phagocytic activity was observed by microscopy. RESULTS: NO production increased after 48 h exposure at 2450 MHz, compared with controls. The group subjected to the combined interaction of two RFs showed an increase of HSP70 after 48 h exposure and a significant increase of NO and TNF-α after 72 h. The phagocytic activity of macrophages decreased in all groups as exposure time increased. CONCLUSIONS: Our results indicated a decrease in phagocytic activity and an increase in inflammatory, cytoprotective, and cytotoxic responses in macrophages after continuous and combined exposure of multiple RF signals. Multiple RF interact in everyday life, the immune response in humans is unknown.

López-Martín, E., Bregains, J., Relova-Quinteiro, J.L., Cadarso-Suárez, C., Jorge-Barreiro, F.J., Ares-Pena, F.J. The action of pulse-modulated GSM radiation increases regional changes in brain activity and c-Fos expression in cortical and subcortical areas in a rat model of picrotoxin-induced seizure proneness. J Neurosci Res. 87:1484-1499, 2009.

The action of the pulse-modulated GSM radiofrequency of mobile phones has been suggested as a physical phenomenon that might have biological effects on the mammalian central nervous system. In the present study, GSM-exposed picrotoxin-pretreated rats showed differences in clinical and EEG signs, and in c-Fos expression in the brain, with respect to picrotoxin-treated rats exposed to an equivalent dose of unmodulated radiation. Neither radiation treatment caused tissue heating, so thermal effects can be ruled out. The most marked effects of GSM radiation on c-Fos expression in picrotoxin-treated rats were observed in limbic structures, olfactory cortex areas and subcortical areas, the dentate gyrus, and the central lateral nucleus of the thalamic intralaminar nucleus group. Nonpicrotoxin-treated animals exposed to unmodulated radiation showed the highest levels of neuronal c-Fos expression in cortical areas. These results suggest a specific effect of the pulse modulation of GSM radiation on brain activity of a picrotoxin-induced seizure-proneness rat model and indicate that this mobile-phone-type radiation might induce regional changes in previous preexcitability conditions of neuronal activation.

Manta AK, Stravopodis DJ, Papassideri IS, Margaritis LH. Reactive oxygen species elevation and recovery in Drosophila bodies and ovaries following short-term and long-term exposure to DECT base EMF. Electromagn Biol Med. 33(2):118-131, 2014.

The objective of this study was to approach the basic mechanism(s) underlying reported ovarian apoptotic cell death and fecundity decrease induced by nonionizing radiation (NIR) in Drosophila melanogaster. ROS (Reactive Oxygen Species) levels were measured in the bodies and the ovaries of (sexually mature) 4-day-old flies, following exposure for 0.5, 1, 6, 24 and 96 h to a wireless DECT (Digital Enhanced Cordless Telephone) base radiation (1.88-1.90 GHz). Electrical field intensity was 2.7 V/m, measured within the fly vials and calculated SAR (Specific Absorption Rate) value = 0.009 W/Kg. Male and female bodies showed twofold increase in ROS levels ($p < 0.001$) after 6 h of exposure, slightly increasing with more irradiation (24 and 96 h). Ovaries of exposed females had a quick response in ROS increase after 0.5 h (1.5-fold, $p < 0.001$), reaching 2.5-fold after 1 h with no elevation thereafter at 6, 24 and 96 h. ROS levels returned to normal, in the male and the female bodies 24 h after 6 h of exposure of the flies ($p < 0.05$) and in the ovaries 4 h after 1 h exposure of the females ($p < 0.05$). It is postulated that the pulsed (at 100 Hz rate and 0.08 ms duration) idle state of the DECT base radiation is capable of inducing free radical formation albeit the very low SAR, leading rapidly to accumulation of ROS in a level-saturation manner under continuous exposure, or in a recovery manner after interruption of radiation, possibly due to activation of the antioxidant machinery of the organism.

Manta AK, Stravopodis DJ, Papassideri IS, Margaritis LH. Reactive oxygen species elevation and recovery in Drosophila bodies and ovaries following short-term and long-term exposure to DECT base EMF. Electromagn Biol Med. 33(2):118-131, 2014.

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Manta AK, Papadopoulou D, Polyzos AP, Fragopoulou AF, Skouroliakou AS, Thanos D, Stravopodis DJ, Margaritis LH. Mobile-phone radiation-induced perturbation of gene-expression profiling, redox equilibrium and sporadic-apoptosis control in the ovary of Drosophila melanogaster. Fly (Austin). 11(2):75-95, 2017.

The daily use by people of wireless communication devices has increased exponentially in the last decade, begetting concerns regarding its potential health hazards. Drosophila melanogaster

four days-old adult female flies were exposed for 30 min to radiation emitted by a commercial mobile phone at a SAR of 0.15 W/kg and a SAE of 270 J/kg. ROS levels and apoptotic follicles were assayed in parallel with a genome-wide microarrays analysis. ROS cellular contents were found to increase by 1.6-fold (x), immediately after the end of exposure, in follicles of pre-choriogenic stages (germarium - stage 10), while sporadically generated apoptotic follicles (germarium 2b and stages 7-9) presented with an averaged 2x upregulation in their sub-population mass, 4 h after fly's irradiation with mobile device. Microarray analysis revealed 168 genes being differentially expressed, 2 h post-exposure, in response to radiofrequency (RF) electromagnetic field-radiation exposure (≥1.25x, $P < 0.05$) and associated with multiple and critical biological processes, such as basic metabolism and cellular subroutines related to stress response and apoptotic death. Exposure of adult flies to mobile-phone radiation for 30 min has an immediate impact on ROS production in animal's ovary, which seems to cause a global, systemic and non-targeted transcriptional reprogramming of gene expression, 2 h post-exposure, being finally followed by induction of apoptosis 4 h after the end of exposure. Conclusively, this unique type of pulsed radiation, mainly being derived from daily used mobile phones, seems capable of mobilizing critical cytopathic mechanisms, and altering fundamental genetic programs and networks in D. melanogaster.

Marinelli, F., La Sala, D., Cicciotti, G., Cattini, L., Trimarchi, C., Putti, S., Zamparelli, A., Giuliani, L., Tomassetti, G., Cinti ,C. Exposure to 900 MHz electromagnetic field induces an unbalance between pro-apoptotic and pro-survival signals in T-lymphoblastoid leukemia CCRF-CEM cells. J Cell Physiol. 198:324-332, 2004.

It has been recently established that low-frequency electromagnetic field (EMFs) exposure induces biological changes and could be associated with increased incidence of cancer, while the issue remains unresolved as to whether high-frequency EMFs can have hazardous effect on health. Epidemiological studies on association between childhood cancers, particularly leukemia and brain cancer, and exposure to low- and high-frequency EMF suggested an etiological role of EMFs in inducing adverse health effects. To investigate whether exposure to high-frequency EMFs could affect in vitro cell survival, we cultured acute T-lymphoblastoid leukemia cells (CCRF-CEM) in the presence of unmodulated 900 MHz EMF, generated by a transverse electromagnetic (TEM) cell, at various exposure times. We evaluated the effects of high-frequency EMF on cell growth rate and apoptosis induction, by cell viability (MTT) test, FACS analysis and DNA ladder, and we investigated pro-apoptotic and pro-survival signaling pathways possibly involved as a function of exposure time by Western blot analysis. At short exposure times (2-12 h), unmodulated 900 MHz EMF induced DNA breaks and early activation of both p53-dependent and -independent apoptotic pathways while longer continuous exposure (24-48 h) determined silencing of pro-apoptotic signals and activation of genes involved in both intracellular (Bcl-2) and extracellular (Ras and Akt1) pro-survival signaling. Overall our results indicate that exposure to 900 MHz continuous wave, after inducing an early self-defense response triggered by DNA damage, could confer to the survivor CCRF-CEM cells a further advantage to survive and proliferate.

Markovà, E., Hillert, L., Malmgren, L., Persson, B.R., Belyaev, I.Y. Microwaves from GSM mobile telephones affect 53BP1 and gamma-H2AX foci in human lymphocytes from hypersensitive and healthy persons. Environ Health Perspect. 113:1172-1177, 2005.

The data on biologic effects of nonthermal microwaves (MWs) from mobile telephones are diverse, and these effects are presently ignored by safety standards of the International Commission for Non-Ionizing Radiation Protection (ICNIRP). In the present study, we investigated effects of MWs of Global System for Mobile Communication (GSM) at different carrier frequencies on human lymphocytes from healthy persons and from persons reporting hypersensitivity to electromagnetic fields (EMFs). We measured the changes in chromatin conformation, which are indicative of stress response and genotoxic effects, by the method of anomalous viscosity time dependence, and we analyzed tumor suppressor p53-binding protein 1 (53BP1) and phosphorylated histone H2AX (gamma-H2AX), which have been shown to colocalize in distinct foci with DNA double-strand breaks (DSBs), using immunofluorescence confocal laser microscopy. We found that MWs from GSM mobile telephones affect chromatin conformation and 53BP1/gamma-H2AX foci similar to heat shock. For the first time, we report here that effects of MWs from mobile telephones on human lymphocytes are dependent on carrier frequency. On average, the same response was observed in lymphocytes from hypersensitive and healthy subjects.

Markovà, E., Malmgren, L.O., Belyaev, I.Y. Microwaves from mobile phones inhibit 53 BP1focus formation in human stem cells more strongly than in differentiated cells: possible mechanistic link to cancer risk. Environ Health Perspect. 118:394-399, 2010.

Background: It is widely accepted that DNA double-strand breaks (DSBs) and their misrepair in stem cells are critical events in the multistage origination of various leukemias and tumors, including gliomas. **Objectives:** We studied whether microwaves from mobile telephones of the Global System for Mobile Communication (GSM) and the Universal Global Telecommunications System (UMTS) induce DSBs or affect DSB repair in stem cells. **Methods:** We analyzed tumor suppressor TP53 binding protein 1 (53BP1) foci that are typically formed at the sites of DSB location (referred to as DNA repair foci) by laser confocal microscopy. **Results:** Microwaves from mobile phones inhibited formation of 53BP1 foci in human primary fibroblasts and mesenchymal stem cells. These data parallel our previous findings for human lymphocytes. Importantly, the same GSM carrier frequency (915 MHz) and UMTS frequency band (1947.4 MHz) were effective for all cell types. Exposure at 905 MHz did not inhibit 53BP1 foci in differentiated cells, either fibroblasts or lymphocytes, whereas some effects were seen in stem cells at 905 MHz. Contrary to fibroblasts, stem cells did not adapt to chronic exposure during 2 weeks. **Conclusions:** The strongest microwave effects were always observed in stem cells. This result may suggest both significant misbalance in DSB repair and severe stress response. Our findings that stem cells are most sensitive to microwave exposure and react to more frequencies than do differentiated cells may be important for cancer risk assessment and indicate that stem cells are the most relevant cellular model for validating safe mobile communication signals.

Meena R, Kumari K, Kumar J, Rajamani P, Verma HN, Kesari KK. Therapeutic approaches of melatonin in microwave radiations-induced oxidative stress-mediated toxicity on male fertility pattern of Wistar rats. Electromagn Biol Med. 33(2):81-91, 2014.

Microwave (MW) radiation produced by wireless telecommunications and a number of electrical devices used in household or in healthcare institutions may adversely affects the reproductive

pattern. Present study aimed to investigate the protective effects of melatonin (is well known antioxidant that protects DNA, lipids and proteins from free radical damage) against oxidative stress-mediated testicular impairment due to long-term exposure of MWs. For this, 70-day-old male Wistar rats were divided into four groups (n = 6/group): Sham exposed, Melatonin (Mel) treated (2 mg/kg), 2.45 GHz MWs exposed and MWs + Mel treated. Exposure took place in Plexiglas cages for 2 h a day for 45 days where, power density (0.21 mW/cm^2) and specific absorption rate (SAR 0.14 W/Kg) were estimated. After the completion of exposure period, rats were sacrificed and various stress related parameters, that is LDH-X (lactate dehydrogenase isoenzyme) activity, xanthine oxidase (XO), ROS (reactive oxygen species), protein carbonyl content, DNA damage and MDA (malondialdehyde) were performed. Result shows that melatonin prevent oxidative damage biochemically by significant increase ($p < 0.001$) in the levels of testicular LDH-X, decreased ($p < 0.001$) levels of MDA and ROS in testis ($p < 0.01$). Meanwhile, it reversed the effects of MWs on XO, protein carbonyl content, sperm count, testosterone level and DNA fragmentation in testicular cells. These results concluded that the melatonin has strong antioxidative potential against MW induced oxidative stress mediated DNA damage in testicular cells.

Megha, K., Deshmukh, P.S., Banerjee, B.D., Tripathi, A.K., Abegaonkar, M.P. Microwave radiation induced oxidative stress, cognitive impairment and inflammation in brain of Fischer rats. Indian J Exp Biol. 50:889-896, 2012.

Public concerns over possible adverse effects of microwave radiation emitted by mobile phones on health are increasing. To evaluate the intensity of oxidative stress, cognitive impairment and inflammation in brain of Fischer rats exposed to microwave radiation, male Fischer-344 rats were exposed to 900 MHz microwave radiation (SAR = 5.953 x 10(-4) W/kg) and 1800 MHz microwave radiation (SAR = 5.835 x 10(-4) W/kg) for 30 days (2 h/day). Significant impairment in cognitive function and induction of oxidative stress in brain tissues of microwave exposed rats were observed in comparison with sham exposed groups. Further, significant increase in level of cytokines (IL-6 and TNF-alpha) was also observed following microwave exposure. Results of the present study indicated that increased oxidative stress due to microwave exposure may contribute to cognitive impairment and inflammation in brain.

Megha, K., Deshmukh,P.S., Ravi, A.K., Tripathi, A.K., Abegaonkar, M.P., Banerjee, B.D. Effect of low-intensity microwave radiation on monoamine neurotransmitters and their key regulating enzymes in rat brain. Cell Biochem Biophys. 73:93-100, 2015a.

The increasing use of wireless communication devices has raised major concerns towards deleterious effects of microwave radiation on human health. The aim of the study was to demonstrate the effect of low-intensity microwave radiation on levels of monoamine neurotransmitters and gene expression of their key regulating enzymes in brain of Fischer rats. Animals were exposed to 900 MHz and 1800 MHz microwave radiation for 30 days (2 h/day, 5 days/week) with respective specific absorption rates as 5.953 × 10(-4) and 5.835 × 10(-4) W/kg. The levels of monoamine neurotransmitters viz. dopamine (DA), norepinephrine (NE), epinephrine (E) and serotonin (5-HT) were detected using LC-MS/MS in hippocampus of all experimental animals. In addition, mRNA expression of key regulating enzymes for these neurotransmitters viz. tyrosine hydroxylase (TH) (for DA, NE and E) and tryptophan

hydroxylase (TPH1 and TPH2) (for serotonin) was also estimated. Results showed significant reduction in levels of DA, NE, E and 5-HT in hippocampus of microwave-exposed animals in comparison with sham-exposed (control) animals. In addition, significant downregulation in mRNA expression of TH, TPH1 and TPH2 was also observed in microwave-exposed animals ($p < 0.05$). In conclusion, the results indicate that low-intensity microwave radiation may cause learning and memory disturbances by altering levels of brain monoamine neurotransmitters at mRNA and protein levels.

Megha, K., Deshmukh, P.S., Banerjee, B.D., Tripathi, A.K., Ahmed, R., Abegaonkar, M.P. Low intensity microwave radiation induced oxidative stress, inflammatory response and DNA damage in rat brain. NeuroToxicol. 51:158-165, 2015b.

Over the past decade people have been constantly exposed to microwave radiation mainly from wireless communication devices used in day to day life. Therefore, the concerns over potential adverse effects of microwave radiation on human health are increasing. Until now no study has been proposed to investigate the underlying causes of genotoxic effects induced by low intensity microwave exposure. Thus, the present study was undertaken to determine the influence of low intensity microwave radiation on oxidative stress, inflammatory response and DNA damage in rat brain. The study was carried out on 24 male Fischer 344 rats, randomly divided into four groups (n=6 in each group): group I consisted of sham exposed (control) rats, group II-IV consisted of rats exposed to microwave radiation at frequencies 900, 1800 and 2450 MHz, specific absorption rates (SARs) 0.59, 0.58 and 0.66 mW/kg, respectively in gigahertz transverse electromagnetic (GTEM) cell for 60 days (2h/day, 5 days/week). Rats were sacrificed and decapitated to isolate hippocampus at the end of the exposure duration. Low intensity microwave exposure resulted in a frequency dependent significant increase in oxidative stress markers viz. malondialdehyde (MDA), protein carbonyl (PCO) and catalase (CAT) in microwave exposed groups in comparison to sham exposed group ($p<0.05$). Whereas, levels of reduced glutathione (GSH) and superoxide dismutase (SOD) were found significantly decreased in microwave exposed groups ($p<0.05$). A significant increase in levels of pro-inflammatory cytokines (IL-2, IL-6, TNF-α, and IFN-γ) was observed in microwave exposed animal ($p<0.05$). Furthermore, significant DNA damage was also observed in microwave exposed groups as compared to their corresponding values in sham exposed group ($p<0.05$). In conclusion, the present study suggests that low intensity microwave radiation induces oxidative stress, inflammatory response and DNA damage in brain by exerting a frequency dependent effect. The study also indicates that increased oxidative stress and inflammatory response might be the factors involved in DNA damage following low intensity microwave exposure.

Migdal P, Bieńkowski P, Cebrat M, Berbeć E, Plotnik M, Murawska A, Sobkiewicz P, Łaszkiewicz A, Latarowski K. Exposure to a 900 MHz electromagnetic field induces a response of the honey bee organism on the level of enzyme activity and the expression of stress-related genes. PLoS One 18(5):e0285522, 2023.

There are many artificial sources of radiofrequency electromagnetic field (RF-EMF) in the environment, with a value between 100 MHz and 6 GHz. The most frequently used signal is with

a frequency of around 900 MHz. The direction of these changes positively impacts the quality of life, enabling easy communication from almost anywhere in the world. All living organisms in the world feel the effects of the electromagnetic field on them. The observations regarding the influence of a RF-EMF on honey bees, describing the general impact of RF-EMF on the colony and/or behavior of individual bees, such as reduction in the number of individuals in colonies, extended homing flight duration, decrease in breeding efficiency, changes in flight direction (movement of bees toward the areas affected by RF-EMF), increase in the intensity and frequency of sounds characteristic for those announcing the impending danger. In this work, we describe the changes in the levels of some of the stress-related markers in honey bees exposed to varying intensities and duration of RF-EMF. One-day-old honeybee worker bees were used for the study. The bees were randomly assigned to 9 experimental groups which were exposed to the following 900 MHz EMF intensities: 12 V/m, 28 V/m, and 61 V/m for 15 min, 1 h and 3 h. The control group was not exposed to the RF-EMF. Each experimental group consisted of 10 cages in which were 100 bees. Then, hemolymph was collected from the bees, in which the activity was assessed AST, ALT, ALP, GGTP, and level of nonenzymatic antioxidants albumin, creatinine, uric acid, and urea. Bees were also collected for the analysis of rps5, ppo, hsp10, hsp70, hsp90, and vitellogenin gene expression. Our study shows that exposure to a 900 MHz electromagnetic field induces a response in the honey bees that can be detected in the level of enzyme activity and the expression of stress-related genes. The response is similar to the one previously described as a result of exposition to UVB irradiation and most likely cannot be attributed to increased temperature.

Misa Agustiño, M.J., Leiro, J.M., Mora, M.T.J., Rodríguez-González, J.A., Barreiro, F.J.J., Ares-Pena, F.J., López-Martín, E. Electromagnetic fields at 2.45 GHz trigger changes in heat shock proteins 90 and 70 without altering apoptotic activity in rat thyroid gland. Biol Open. 1:831-838, 2012.

Non-ionizing radiation at 2.45 GHz may modify the expression of genes that codify heat shock proteins (HSP) in the thyroid gland. Using the enzyme-linked immunosorbent assay (ELISA) technique, we studied levels of HSP-90 and HSP-70. We also used hematoxilin eosin to look for evidence of lesions in the gland and applied the DAPI technique of fluorescence to search for evidence of chromatin condensation and nuclear fragmentation in the thyroid cells of adult female Sprague-Dawley rats. Fifty-four rats were individually exposed for 30 min to 2.45 GHz radiation in a Gigahertz transverse electromagnetic (GTEM) cell at different levels of non-thermal specific absorption rate (SAR), which was calculated using the finite difference time domain (FDTD) technique. Ninety minutes after radiation, HSP-90 and HSP-70 had decreased significantly ($P<0.01$) after applying a SAR of 0.046±1.10 W/Kg or 0.104±5.10(-3) W/Kg. Twenty-four hours after radiation, HSP-90 had partially recovered and HSP-70 had recovered completely. There were few indications of lesions in the glandular structure and signs of apoptosis were negative in all radiated animals. The results suggest that acute sub-thermal radiation at 2.45 GHz may alter levels of cellular stress in rat thyroid gland without initially altering their anti-apoptotic capacity.

Mohammed, H.S., Fahmy, H.M., Radwah, N.M., Elsayed, A.A. Non-thermal continuous and modulated electromagnetic radiation fields effects on sleep EEG of rats. J Adv Res. 4:81-187, 2013.

In the present study, the alteration in the sleep EEG in rats due to chronic exposure to low-level non-thermal electromagnetic radiation was investigated. Two types of radiation fields were used; 900 MHz unmodulated wave and 900 MHz modulated at 8 and 16 Hz waves. Animals has exposed to radiation fields for 1 month (1 h/day). EEG power spectral analyses of exposed and control animals during slow wave sleep (SWS) and rapid eye movement sleep (REM sleep) revealed that the REM sleep is more susceptible to modulated radiofrequency radiation fields (RFR) than the SWS. The latency of REM sleep increased due to radiation exposure indicating a change in the ultradian rhythm of normal sleep cycles. The cumulative and irreversible effect of radiation exposure was proposed and the interaction of the extremely low frequency radiation with the similar EEG frequencies was suggested.

Nakamura, H, Seto, T, Hatta, K, Matsuzaki, I, Nagase, H, Yoshida, M, Ogino, K, Natural killer cell activity reduced by microwave exposure during pregnancy is mediated by opioid systems. Environ Res 79(2):106-113, 1998.

We have previously demonstrated immunosuppression including reduced splenic natural killer cell activity (NKCA) in pregnant rats exposed to microwaves produced mainly by their thermal action. To examine the involvement of opioid systems in reduced NKCA in pregnant rats exposed to microwaves at a relatively low level (2 mW/cm^2 incident power density at 2450 MHz for 90 min), we assayed beta-endorphin (betaEP) in blood, pituitary lobes, and placenta as well as splenic NKCA in virgin and/or pregnant rats. Although microwaves elevated colonic temperatures by 0.8 degreesC for virgin and 0.9 degreesC for pregnant rats, and betaEP in blood and anterior pituitary lobes (AP) significantly, it did not change blood corticosterone as an index of hypothalamic-pituitary adrenal axis. There were significant interactions between pregnancy and microwave exposure on splenic NKCA, betaEP in both blood and AP, and blood progesterone. Intra-peritoneal administration of opioid receptor antagonist naloxone prior to microwave exposure increased NKCA, blood, and placental betaEP in pregnant rats. Alterations in splenic NKCA, betaEP and progesterone in pregnant rats exposed to microwaves may be due to both thermal and nonthermal actions. <u>These results suggest that NKCA reduced by microwaves during pregnancy is mediated by the pituitary opioid system.</u>

Navakatikian, M.A., Tomashevskaya, L.A. Phasic behavioral and endocrine effects of microwaves of nonthermal intensity. In “Biological Effects of Electric and Magnetic Fields, Volume 1," D.O. Carpenter (ed) Academic Press, San Diego, CA, 1994, pp.333-342.

Microwaves at nonthermal levels are able to induce behavioral and endocrine changes at low power densities (0.01-0.1 mW/cm^2). Our studies have demonstrated several phases of inhibition and activation. We suggest that inhibition of behavior by microwaves has many mechanisms depending on the strength and duration of exposure, and most inhibitory effects from direct actions on the nervous system. Activation, on the other hand, is correlated well with decreases in serum concentrations of testosterone and insulin. CW microwaves, however, have no influence on the secretion of insulin.

Naziroğlu M, Gümral N. Modulator effects of L-carnitine and selenium on wireless devices (2.45 GHz)-induced oxidative stress and electroencephalography records in brain of rat. Int J Radiat Biol. 85(8):680-689, 2009.

PURPOSE: Electromagnetic radiation (EMR) from wireless devices may affect biological systems by increasing free radicals. The present study was designed to determine the effects of 2.45 GHz EMR on the brain antioxidant redox system and electroencephalography (EEG) records in rat. The possible protective effects of selenium and L-carnitine were also tested and compared to untreated controls. MATERIALS AND METHODS: Thirty rats were equally divided into five different groups, namely Group A(1): Cage control, Group A(2): Sham control, group B: 2.45 GHz EMR, group C: 2.45 GHz EMR + selenium, group D: 2.45 GHz EMR + L-carnitine. Groups B, C and D were exposed to 2.45 GHz EMR during 60 min/day for 28 days. End of the experiments, EEG records and the brain cortex samples were taken. RESULTS: The cortex brain vitamin A ($p < 0.05$), vitamin C ($p < 0.01$) and vitamin E ($p < 0.05$) concentrations values were lower in group B than in group A1 and A2 although their concentrations were increased by selenium and L-carnitine supplementation. Lipid peroxidation, levels were lower in group C ($p < 0.05$) and D ($p < 0.01$) than in group B where as reduced glutathione levels were higher in group C ($p < 0.05$) than in group A1, A2 and B. However, B-carotene levels did not change in the five groups. CONCLUSIONS: L-carnitine and selenium seem to have protective effects on the 2.45 GHz-induced decrease of the vitamins by supporting antioxidant redox system. L-carnitine on the vitamin concentrations seems to more protective affect than in selenium.

Nazıroğlu, M., Ciğ, B., Doğan, S., Uğuz, A.C., Dilek, S., Faouzi, D. 2.45-Gz wireless devices induce oxidative stress and proliferation through cytosolic Ca^{2+} influx in human leukemia cancer cells. Int J Radiat Biol. 88:449-456, 2012a.

Purpose: Electromagnetic radiation from wireless devices may affect biological systems by increasing free radicals. The present study was designed to determine the effects of 2.45 GHz radiation on the antioxidant redox system, calcium ion signaling, cell count and viability in human leukemia 60 cells. **Materials and methods:** Twelve cell cultures were equally divided into two main groups as controls (n = 6) and irradiated (n = 6) and then subdivided into four different subgroups depending on the duration of exposure, namely 1, 2, 12 and 24 hours. The samples were analyzed immediately after the experimental period. **Results:** The extent of lipid peroxidation, cytosolic free Ca^{2+} and cell numbers were higher in 2.45 GHz groups than in the controls. The increase of cytosolic free Ca^{2+} concentrations was radiation time-dependent and was highest at 24-h exposure. The reduced glutathione, glutathione peroxidase, vitamin C and cell viability values did not show any changes in any of the experimental groups. 2-aminoethyl diphenylborinate inhibits Ca^{2+} ions influx by blockage of the transient receptor potential melastatin 2. **Conclusions:** 2.45 GHz electromagnetic radiation appears to induce proliferative effects through oxidative stress and Ca^{2+} influx although blocking of transient receptor potential melastatin 2 channels by 2-aminoethyl diphenylborinate seems to counteract the effects on Ca^{2+} ions influx.

Nazıroğlu M, Çelik Ö, Özgül C, Çiğ B, Doğan S, Bal R, Gümral N, Rodríguez AB, Pariente JA. Melatonin modulates wireless (2.45 GHz)-induced oxidative injury through TRPM2 and voltage gated Ca(2+) channels in brain and dorsal root ganglion in rat. Physiol Behav. 105(3):683-692, 2012b.

We aimed to investigate the protective effects of melatonin and 2.45 GHz electromagnetic radiation (EMR) on brain and dorsal root ganglion (DRG) neuron antioxidant redox system, Ca(2+) influx, cell viability and electroencephalography (EEG) records in the rat. Thirty two rats were equally divided into four different groups namely group A1: Cage control, group A2: Sham control, group B: 2.45 GHz EMR, group C: 2.45 GHz EMR+melatonin. Groups B and C were exposed to 2.45 GHz EMR during 60 min/day for 30 days. End of the experiments, EEG records and the brain cortex and DRG samples were taken. Lipid peroxidation (LP), cell viability and cytosolic Ca(2+) values in DRG neurons were higher in group B than in groups A1 and A2 although their concentrations were increased by melatonin, 2-aminoethyldiphenyl borinate (2-APB), diltiazem and verapamil supplementation. Spike numbers of EEG records in group C were lower than in group B. Brain cortex vitamin E concentration was higher in group C than in group B. In conclusion, Melatonin supplementation in DRG neurons and brain seems to have protective effects on the 2.45 GHz-induced increase Ca(2+) influx, EEG records and cell viability of the hormone through TRPM2 and voltage gated Ca(2+) channels.

Nittby, H., Widegren, B., Krogh, M., Grafström, G., Berlin, H., Rehn, G., Eberhardt, J.L., Malmgren, L., Persson, B.R.R., Salford, L. Exposure to radiation from global system for mobile communications at 1,800 MHz significantly changes gene expression in rat hippocampus and cortex. Environmentalist. 28: 458-465, 2008a.

We have earlier shown that radio frequency electromagnetic fields can cause significant leakage of albumin through the blood–brain barrier of exposed rats as compared to non-exposed rats, and also significant neuronal damage in rat brains several weeks after a 2 h exposure to a mobile phone, at 915 MHz with a global system for mobile communications (GSM) frequency modulation, at whole-body specific absorption rate values (SAR) of 200, 20, 2, and 0.2 mW/kg. We have now studied whether 6 h of exposure to the radiation from a GSM mobile test phone at 1,800 MHz (at a whole-body SAR-value of 13 mW/kg, corresponding to a brain SAR-value of 30 mW/kg) has an effect upon the gene expression pattern in rat brain cortex and hippocampus—areas where we have observed albumin leakage from capillaries into neurons and neuronal damage. Microarray analysis of 31,099 rat genes, including splicing variants, was performed in cortex and hippocampus of 8 Fischer 344 rats, 4 animals exposed to global system for mobile communications electromagnetic fields for 6 h in an anechoic chamber, one rat at a time, and 4 controls kept as long in the same anechoic chamber without exposure, also in this case one rat at a time. Gene ontology analysis (using the gene ontology categories biological processes, molecular functions, and cell components) of the differentially expressed genes of the exposed animals versus the control group revealed the following highly significant altered gene categories in both cortex and hippocampus: extracellular region, signal transducer activity, intrinsic to membrane, and integral to membrane. The fact that most of these categories are connected with membrane functions may have a relation to our earlier observation of albumin transport through brain capillaries

Nittby, H., Grafström, G., Tian, D.P., Malmgren, L., Brun, A., Persson, B.R.R., Salford, L.G., Eberhardt, J. Cognitive impairment in rats after long-term exposure to GSM-900 mobile phone radiation. Bioelectromagnetics. 29:219-232, 2008b.

Considering the frequent use of mobile phones, we have directed attention to possible implications on cognitive functions. In this study we investigated in a rat model the long-term effects of protracted exposure to Global System for Mobile Communication-900 MHz (GSM-900) radiation. Out of a total of 56 rats, 32 were exposed for 2 h each week for 55 weeks to radio-frequency electromagnetic radiation at different SAR levels (0.6 and 60 mW/kg at the initiation of the experimental period) emitted by a (GSM-900) test phone. Sixteen animals were sham exposed and eight animals were cage controls, which never left the animal house. After this protracted exposure, GSM-900 exposed rats were compared to sham exposed controls. Effects on exploratory behaviour were evaluated in the open-field test, in which no difference was seen. Effects on cognitive functions were evaluated in the episodic-like memory test. In our study, GSM exposed rats had impaired memory for objects and their temporal order of presentation, compared to sham exposed controls ($P = 0.02$). Detecting the place in which an object was presented was not affected by GSM exposure. Our results suggest significantly reduced memory functions in rats after GSM microwave exposure ($P = 0.02$).

Odacı E, Özyılmaz C. Exposure to a 900 MHz electromagnetic field for one hour a day over 30 days does change the histopathology and biochemistry of the rat testis. Int J Radiat Biol. 91(7):541-554, 2015.

PURPOSE: This study investigated the effect of exposure to a 900-megahertz (MHz) electromagnetic field (EMF) on the rat testicle. MATERIALS AND METHODS: Twenty-four adult male rats were divided into control, sham and EMF groups. The EMF group rats were exposed to 900-MHz EMF (1 h / 30 day), and testicles were extracted at the end of the experiment. Malondialdehyde, superoxide dismutase, catalase and glutathione levels and apoptotic index and histopathological damage scores were compared. RESULTS: Histopathologically, EMF group rats exhibited vacuoles in seminiferous tubules basal membrane and edema in the intertubular space. Seminiferous tubule diameters and germinal epithelium thickness were both smaller, and apoptotic index was higher, in the EMF group than in the other groups. Malondialdehyde, superoxide dismutase, catalase and glutathione values in the EMF group decreased significantly compared to those of the control group. CONCLUSIONS: The results show that exposure to 900-MHz EMF causes alterations in adult rat testicular morphology and biochemistry.

Odacı E, Unal D, Mercantepe T, Topal Z, Hancı H, Türedi S, Erol H, Mungan S, Kaya H, Colakoğlu S. Pathological effects of prenatal exposure to a 900 MHz electromagnetic field on the 21-day-old male rat kidney. Biotech Histochem. 90(2):93-101, 2015.

We investigated the effects on kidney tissue of 900 megahertz (MHz) EMF applied during the prenatal period. Pregnant rats were exposed to 900 MHz EMF, 1 h/day, on days 13-21 of pregnancy; no procedure was performed on control group pregnant rats or on mothers or

newborns after birth. On postnatal day 21, kidney tissues of male rat pups from both groups were examined by light and electron microscopy. Malondialdehyde (MDA), superoxide dismutase (SOD), catalase (CAT) and glutathione levels also were investigated. Light microscopy revealed some degenerative changes in the tubule epithelium, small cystic formations in the primitive tubules and large cysts in the cortico-medullary or medullary regions in the experimental group. Electron microscopy revealed a loss of peritubular capillaries and atypical parietal layer epithelial cells in the experimental group. Biochemical analysis showed significantly increased MDA levels in the experimental group and decreased SOD and CAT levels. EMF applied during the prenatal period can caused pathological changes in kidney tissue in 21-day-old male rats owing to oxidative stress and decreased antioxidant enzyme levels.

Odacı, E., Hancı ,H., Yuluğ, E., Türedi, S., Aliyazıcıoğlu, Y., Kaya, H., Çolakoğlu S. Effects of prenatal exposure to a 900 MHz electromagnetic field on 60-day-old rat testis and epididymal sperm quality. Biotech Histochem. 91:9-19, 2016.

We investigated the effects of exposure in utero to a 900 megahertz (MHz) electromagnetic field (EMF) on 60-day-old rat testis and epididymis. Pregnant rats were divided into control (CG; no treatment) and EMF (EMFG) groups. The EMFG was exposed to 900 MHz EMF for 1 h each day during days 13 - 21 of pregnancy. Newborn rats were either newborn CG (NCG) or newborn EMF groups (NEMFG). On postnatal day 60, a testis and epididymis were removed from each animal. Epididymal semen quality, and lipid and DNA oxidation levels, apoptotic index and histopathological damage to the testis were compared. We found a higher apoptotic index, greater DNA oxidation levels and lower sperm motility and vitality in the NEMFG compared to controls. Immature germ cells in the seminiferous tubule lumen, and altered seminiferous tubule epithelium and seminiferous tubule structure also were observed in hematoxylin and eosin stained sections of NEMFG testis. Nuclear changes that indicated apoptosis were identified in TUNEL stained sections and large numbers of apoptotic cells were observed in most of the seminiferous tubule epithelium in the NEMFG. Sixty-day-old rat testes exposed to 900 MHz EMF exhibited altered sperm quality and biochemical characteristics.

Okatan DÖ, Kaya H, Aliyazıcıoğlu Y, Demir S, Çolakoğlu S, Odacı E. Continuous 900-megahertz electromagnetic field applied in middle and late-adolescence causes qualitative and quantitative changes in the ovarian morphology, tissue and blood biochemistry of the rat. Int J Radiat Biol 94(2):186-198, 2018.

Purpose: The purpose of this study was to use histological and biochemical methods in order to evaluate changes taking place in the ovarian of rats exposed to the effect of a 900-megahertz (MHz) electromagnetic field (EMF) in middle and late adolescence. **Materials and methods:** Twenty-four 34-d-old female Sprague-Dawley rats were assigned equally to control, sham and EMF groups. EMF group rats were exposed to the effect of a 900-MHz EMF for 1 h a day, at the same time every day between postnatal days 35 and 59, while inside an EMF cage. Sham group rats were kept inside the EMF cage for the same time between postnatal days 35 and 59 without being exposed to any EMF effect. At the end of the study, rats' ovarian were removed and blood specimens were taken. Right ovarium tissues were subjected to routine histological procedures and stained with hematoxylin and eosin, periodic acid shift and Masson's trichrome. Follicles were counted in ovarian sections stained with hematoxylin and eosin. The TUNEL

method was used to evaluate apoptosis. Left ovarian tissue and blood specimens were investigated biochemically. **Results:** Histopathological examination of EMF group ovarian tissue revealed thinning in the zona granulosa and theca layers, shrinking in granulosa cells, reduced mitotic activity and leukocyte infiltration in the follicles and stroma. Secondary follicle numbers in the EMF group were significantly lower than in the other groups. In terms of biochemistry, EMF and sham group superoxide dismutase, catalase and anti-Mullerian hormone levels and EMF group 3-nitrotyrosine values increased significantly compared to the control group. EMF and sham group serum catalase and 8-hydroxy-deoxiguanosine values increased significantly compared to the control group, and EMF group total oxidant status and oxidative stress index values were significantly higher compared to the sham and control groups. **Conclusions:** A total of 900-MHz EMF applied in middle and late adolescence may cause changes in the morphology and biochemistry of the rat ovarium.

Okatan DÖ, Kulaber A, Kerimoglu G, Odacı E. Altered morphology and biochemistry of the female rat liver following 900 megahertz electromagnetic field exposure during mid to late adolescence. Biotech Histochem. 94(6):420-428, 2019.

Despite their benefits, technological devices such as cell phones may also have deleterious effects on human health. Considerable debate continues concerning the effects of the electromagnetic field (EMF) emitted during cell phone use on human health. We investigated the effects of exposure to 900 megahertz (MHz) EMF during mid to late adolescence on the rat liver. Control (ContGr), sham (ShmGr) and EMF (EMFGr) groups of female rats were established. We exposed the EMFGr rats daily to 900 MHz EMF on postnatal days 35-59. ShmGr rats underwent sham procedures. No procedure was performed on ContGr rats. Rats were sacrificed on postnatal day 60 and the livers were extracted. One part of the liver was stained with Masson's trichrome or hematoxylin and eosin. The remaining tissue was used to measure oxidative stress markers including malondialdehyde, glutathione, catalase, superoxide dismutase, 8-hydroxydeoxyguanosine (8-OHdG) and nitrotyrosine. Total antioxidant status and total oxidant status were used to calculate the oxidative stress index. We found normal hepatic morphology in the ContGr and ShmGr groups. The EMFGr group exhibited occasional irregularities in the radial arrangement of hepatocytes, cytoplasmic vacuolization, hemorrhage, sinusoid expansion, hepatocyte morphology and edema. Biochemical analysis revealed that 8-OHdG and SOD levels in EMFGr decreased significantly compared to the ContGr and ShmGr groups. Exposure to a continuous 900 MHz EMF for 1 h daily during mid to late adolescence may cause histopathological and biochemical alterations in hepatic tissue.

Oksay T, Naziroğlu M, Doğan S, Güzel A, Gümral N, Koşar PA. Protective effects of melatonin against oxidative injury in rat testis induced by wireless (2.45 GHz) devices. Andrologia. 46(1):65-72, 2014.

Wireless devices have become part of everyday life and mostly located near reproductive organs while they are in use. The present study was designed to determine the possible protective effects of melatonin on oxidative stress-dependent testis injury induced by 2.45-GHz electromagnetic radiation (EMR). Thirty-two rats were equally divided into four different groups, namely cage control (A1), sham control (A2), 2.45-GHz EMR (B) and 2.45-GHz EMR+melatonin (C). Group B and C were exposed to 2.45-GHz EMR during 60 min day(-1) for 30 days. Lipid peroxidation

levels were higher in Group B than in Group A1 and A2. Melatonin treatment prevented the increase in the lipid peroxidation induced by EMR. Also reduced glutathione (GSH) and glutathione peroxidase (GSH-Px) levels in Group D were higher than that of exposure group. Vitamin A and E concentrations decreased in exposure group, and melatonin prevented the decrease in vitamin E levels. In conclusion, wireless (2.45 GHz) EMR caused oxidative damage in testis by increasing the levels of lipid peroxidation and decreasing in vitamin A and E levels. Melatonin supplementation prevented oxidative damage induced by EMR and also supported the antioxidant redox system in the testis.

Özdemir E, Çömelekoğlu U, Degirmenci E, Bayrak G, Yildirim M, Ergenoglu t T, Yilmaz BC, Yalin S, Koyuncu DD, Ozbay E. The effect of 4.5 G (LTE Advanced-Pro network) mobile phone radiation on the optic nerve. Cutan Ocul Toxicol 40(3):198-206, 2021.

Purpose: Rapid development in mobile phone technologies increase the average mobile phone usage duration. This increase also triggers exposure to radiofrequency radiation (RF), which is a risk factor for the health. In this study, it was aimed to investigate the effect of mobile phone working with LTE-Advanced Pro (4.5 G) mobile network on the optic nerve, which is responsible for the transmission of visual information. **Material and methods:** Thirty-two rats divided into two groups as control (no RF, sham exposure) and experimental (RF exposure using a mobile phone with LTE-Advanced Pro network; 2 hours/day, 6 weeks). The visual evoked potential (VEP) was recorded and determined amplitudes and latencies of VEP waves. Optic nerve malondialdehyde level, catalase and superoxide dismutase activities were determined. Furthermore, ultrastructural and morphometric changes of optic nerve were evaluated **Results:** In VEP recordings, the mean VEP amplitudes of experimental group were significantly lower than control group. In ultrastructural evaluation, myelinated nerve fibres and glial cells were observed in normal histologic appearance both in sham and experimental group. However, by performing morphometric analysis, in the experimental group, axonal diameter and myelin thickness were shown to be lower and the G-ratio was higher than in the sham group. In the experimental group, malondialdehyde level was significantly higher and superoxide dismutase and catalase activities were significantly lower than sham group. There was a high correlation between VEP wave amplitudes and oxidative stress markers. **Conclusion:** Findings obtained in this study support optic nerve damage. These results point out an important risk that may decrease the quality of life.

Ozguner F, Oktem F, Ayata A, Koyu A, Yilmaz HR. A novel antioxidant agent caffeic acid phenethyl ester prevents long-term mobile phone exposure-induced renal impairment in rat. Prognostic value of malondialdehyde, N-acetyl-beta-D-glucosaminidase and nitric oxide determination. Mol Cell Biochem. 277(1-2):73-80, 2005a.

Caffeic acid phenethyl ester (CAPE), a flavonoid like compound, is one of the major components of honeybee propolis. It has been used in folk medicine for many years in Middle East countries. It was found to be a potent free radical scavenger and antioxidant recently. The aim of this study was to examine long-term applied 900 MHz emitting mobile phone-induced oxidative stress that promotes production of reactive oxygen species (ROS) and, was to investigate the role of CAPE on kidney tissue against the possible electromagnetic radiation (EMR)-induced renal impairment

in rats. In particular, the ROS such as superoxide and nitric oxide (NO) may contribute to the pathophysiology of EMR-induced renal impairment. Malondialdehyde (MDA, an index of lipid peroxidation) levels, urinary N-acetyl-beta-D: -glucosaminidase (NAG, a marker of renal tubular injury) and nitric oxide (NO, an oxidant product) levels were used as markers of oxidative stress-induced renal impairment and the success of CAPE treatment. The activities of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px) in renal tissue were determined to evaluate the changes of antioxidant status. The rats used in the study were randomly grouped (10 each) as follows: i) Control group (without stress and EMR), ii) Sham-operated rats stayed without exposure to EMR (exposure device off), iii) Rats exposed to 900 MHz EMR (EMR group), and iv) A 900 MHz EMR exposed + CAPE treated group (EMR + CAPE group). In the EMR exposed group, while tissue MDA, NO levels and urinary NAG levels increased ($p < 0.0001$), the activities of SOD, CAT, and GSH-Px in renal tissue were reduced ($p < 0.001$). CAPE treatment reversed these effects as well ($p < 0.0001$, $p < 0.001$ respectively). In conclusion, the increase in NO and MDA levels of renal tissue, and in urinary NAG with the decrease in renal SOD, CAT, GSH-Px activities demonstrate the role of oxidative mechanisms in 900 MHz mobile phone-induced renal tissue damage, and CAPE, via its free radical scavenging and antioxidant properties, ameliorates oxidative renal damage. These results strongly suggest that CAPE exhibits a protective effect on mobile phone-induced and free radical mediated oxidative renal impairment in rats.

Ozguner F, Altinbas A, Ozaydin M, Dogan A, Vural H, Kisioglu AN, Cesur G, Yildirim NG. Mobile phone-induced myocardial oxidative stress: protection by a novel antioxidant agent caffeic acid phenethyl ester. Toxicol Ind Health. 21:223-230, 2005b.

Electromagnetic radiation (EMR) or radiofrequency fields of cellular mobile phones may affect biological systems by increasing free radicals, which appear mainly to enhance lipid peroxidation, and by changing the antioxidant defense systems of human tissues, thus leading to oxidative stress. Mobile phones are used in close proximity to the heart, therefore 900 MHz EMR emitting mobile phones may be absorbed by the heart. Caffeic acid phenethyl ester (CAPE), one of the major components of honeybee propolis, was recently found to be a potent free radical scavenger and antioxidant, and is used in folk medicine. The aim of this study was to examine 900 MHz mobile phone-induced oxidative stress that promotes production of reactive oxygen species (ROS) and the role of CAPE on myocardial tissue against possible oxidative damage in rats. Thirty rats were used in the study. Animals were randomly grouped as follows: sham-operated control group (N: 10) and experimental groups: (a) group II: 900 MHz EMR exposed group (N: 10); and (b) group III: 900 MHz EMR exposed+CAPE-treated group (N: 10). A 900 MHz EMR radiation was applied to groups II and III 30 min/day, for 10 days using an experimental exposure device. Malondialdehyde (MDA, an index of lipid peroxidation), and nitric oxide (NO, a marker of oxidative stress) were used as markers of oxidative stress-induced heart impairment. Superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px) activities were studied to evaluate the changes of antioxidant status. In the EMR exposed group, while tissue MDA and NO levels increased, SOD, CAT and GSH-Px activities were reduced. CAPE treatment in group III reversed these effects. In this study, the increased levels of MDA and NO and the decreased levels of myocardial SOD, CAT and GSH-Px activities demonstrate the role of oxidative mechanisms in 900 MHz mobile phone-induced heart tissue damage, and CAPE, via its free radical scavenging and antioxidant properties, ameliorates

oxidative heart injury. These results show that CAPE exhibits a protective effect on mobile phone-induced and free radical mediated oxidative heart impairment in rats.

Ozgur, E., Güler, G., Seyhan, N. Mobile phone radiation-induced free radical damage in the liver is inhibited by the antioxidants n-acetyl cysteine and epigallocatechin-gallate. Int J Radiat Biol. 86:935-945, 2010.

Purpose: To investigate oxidative damage and antioxidant enzyme status in the liver of guinea pigs exposed to mobile phone-like radiofrequency radiation (RFR) and the potential protective effects of N-acetyl cysteine (NAC) and epigallocatechin-gallate (EGCG) on the oxidative damage. **Materials and methods:** Nine groups of guinea pigs were used to study the effects of exposure to an 1800-MHz Global System for Mobile Communications (GSM)-modulated signal (average whole body Specific Absorption Rate (SAR) of 0.38 W/kg, 10 or 20 min per day for seven days) and treatment with antioxidants. **Results:** Significant increases in malondialdehyde (MDA) and total nitric oxide (NO(x)) levels and decreases in activities of superoxide dismutase (SOD), myeloperoxidase (MPO) and glutathione peroxidase (GSH-Px) were observed in the liver of guinea pigs after RFR exposure. Only NAC treatment induces increase in hepatic GSH-Px activities, whereas EGCG treatment alone attenuated MDA level. Extent of oxidative damage was found to be proportional to the duration of exposure ($P < 0.05$). **Conclusion:** Mobile phone-like radiation induces oxidative damage and changes the activities of antioxidant enzymes in the liver. The adverse effect of RFR may be related to the duration of mobile phone use. NAC and EGCG protect the liver tissue against the RFR-induced oxidative damage and enhance antioxidant enzyme activities

Ozlem Nisbet H, Nisbet C, Akar A, Cevik M, Karayigit MO. Effects of exposure to electromagnetic field (1.8/0.9 GHz) on testicular function and structure in growing rats. Res Vet Sci. 93(2):1001-1005, 2012.

The aim of our study was to evaluate the possible effects of whole-body electromagnetic field (EMF) exposure on reproduction in growing male rats. Male albino Wistar rats (2 days old) were exposed to EMF 1800 and 900 MHz for 2 h continuously per day for 90 days. Sham control was kept under similar conditions except that the field was not applied for the same period. After blood samples were collected, the animals were sacrificed 24 h after the last exposure and the tissues of interest were harvested. The mean plasma total testosterone showed similarity among the two study groups and was significantly higher than the sham control rats. The percentage of epididymal sperm motility was significantly higher in the 1800 MHz group ($P<0.05$). The morphologically normal spermatozoa rates were higher and the tail abnormality and total percentage abnormalities were lower in the 900 MHz group ($P<0.05$). Histopathologic parameters in the 1800 MHz group were significantly higher ($P<0.05$). In conclusion, the present study indicated that exposure to electromagnetic wave caused an increase in testosterone level, epididymal sperm motility (forward), and normal sperm morphology of rats. As a consequences, 1800 and 900 MHz EMF could be considered to be a cause of precocious puberty in growing rats.

Ozorak A, Nazıroğlu M, Celik O, Yüksel M, Ozçelik D, Ozkaya MO, Cetin H, Kahya MC, Kose SA. Wi-Fi (2.45 GHz)- and mobile phone (900 and 1800 MHz)-induced risks on oxidative stress and elements in kidney and testis of rats during pregnancy and the development of offspring. Biol Trace Elem Res. 156(1-3):221-229, 2013.

The present study was designed to determine the effects of both Wi-Fi (2.45 GHz)- and mobile phone (900 and 1800 MHz)-induced electromagnetic radiation (EMR) on oxidative stress and trace element levels in the kidney and testis of growing rats from pregnancy to 6 weeks of age. Thirty-two rats and their 96 newborn offspring were equally divided into four different groups, namely, control, 2.45 GHz, 900 MHz, and 1800 MHz groups. The 2.45 GHz, 900 MHz, and 1,800 MHz groups were exposed to EMR for 60 min/day during pregnancy and growth. During the fourth, fifth, and sixth weeks of the experiment, kidney and testis samples were taken from decapitated rats. Results from the fourth week showed that the level of lipid peroxidation in the kidney and testis and the copper, zinc, reduced glutathione (GSH), glutathione peroxidase (GSH-Px), and total antioxidant status (TAS) values in the kidney decreased in the EMR groups, while iron concentrations in the kidney as well as vitamin A and vitamin E concentrations in the testis increased in the EMR groups. Results for fifth-week samples showed that iron, vitamin A, and β-carotene concentrations in the kidney increased in the EMR groups, while the GSH and TAS levels decreased. The sixth week results showed that iron concentrations in the kidney and the extent of lipid peroxidation in the kidney and testis increased in the EMR groups, while copper, TAS, and GSH concentrations decreased. There were no statistically significant differences in kidney chromium, magnesium, and manganese concentrations among the four groups. In conclusion, Wi-Fi- and mobile phone-induced EMR caused oxidative damage by increasing the extent of lipid peroxidation and the iron level, while decreasing total antioxidant status, copper, and GSH values. Wi-Fi- and mobile phone-induced EMR may cause precocious puberty and oxidative kidney and testis injury in growing rats.

Ozyilmaz C, Oktay MF, Dasdag S, Ulukaya E, Genel ME, Tansuker HD, Emre F, Yeğin K. Evaluation of the Thyroids of Offsprings Exposed to 2450 MHz Radiofrequency Radiation During Pregnancy: A Sixth Month Data. J Inter Dental Med Res. 17(2): 925-930, 2024.

This study aimed to determine whether the exposure to radiofrequency emitted by wireless internet providers (2450 MHz) throughout the day during rats' pregnancy causes a problem in the thyroid tissues of their offspring. The pregnant rats in the experimental group were exposed to radiofrequency radiation (RFR) (24 hours/day) at a 2450 MHz frequency in pulse wave mode with 1 W output strength by a generator simulating Wi-Fi waves. The offspring in the control and experimental groups were randomized selected (n:8). At the end of the sixth month, the thyroid tissues were removed and evaluated histopathologically and biochemically. Mann–Whitney U-tests and T-tests were used for statistical analysis. The threshold for statistical significance was $p < 0.05$. There was a significant difference in mononuclear cell infiltration ($p=0.03$) and vascular increase in congestion ($p<0.001$). There was no difference in the TUNEL-positive cell percentage ($p=0.62$) and H2A.X antibody levels ($p=0.68$) between the rats in the control and experimental groups. In this study, 2450 MHz RFR exposure during the prenatal

period did not cause a statistically significant difference in terms of H2A.X levels and TUNEL-positive cell percentages in the thyroid tissue of rats.

Özyılmaz C, Daşdağ S, Oktay MF, Ulukaya E, Erkısa Genel M, Emre F, Yeğin K. One-year follow-up of thyroid status in rats exposed to 2.45 Ghz radiofrequency radiation during the prenatal period. Electromagn Biol Med. 2025 Oct 22:1-10. doi: 10.1080/15368378.2025.2577318

The aim of this study is to investigate the thyroid status of offspring exposed to prenatal 2.45 GHz radiofrequency radiation (RFR). In this study, which is the second phase of our previous study, the thyroids of rats exposed to prenatal 2.45 GHz RFR were examined one year after birth. The mothers of the offspring in the experimental group (n = 8) were exposed to 2.45 GHz RFR (whole-body specific absorption rate (SAR): 12 mW/kg; maximum point SAR: 25 mW/kg) 24 hours per day throughout pregnancy. The mothers in the sham group (n = 8) were kept under the same experimental conditions except for RFR exposure. The offspring in this study were not exposed to RFR after birth and continued their daily lives for one year. When the offspring reached one year of age, they were sacrificed and their thyroids were removed and evaluated. Mann-Whitney U and t tests were used for statistical analysis. Increases in fibrosis (p = 0.038), atypical thyrocytes (p = 0.002) and degenerated follicles (p = 0.007) and colloid reduction (p = 0.002) were found to be significant in the experimental group compared to the sham group. However, the increase in the percentage of apoptosis positive cells (p = 0.006) and H2A.X antibody levels (p = 0.007) showed a statistically significant difference in the experimental group compared to the sham group. This study provides evidence that prenatal exposure to 2.45 GHz RFR can induce persistent histological changes, increase apoptosis, and cause DNA double-strand breaks in thyroid tissue observed one year after birth. These results underscore the importance of further long-term studies to assess developmental risks associated with prenatal RFR exposure.

(E) Özyılmaz C, Daşdağ S, Oktay MF, Ulukaya E, Erkısa Genel M, Emre F, Yeğin K. One-year follow-up of thyroid status in rats exposed to 2.45 Ghz radiofrequency radiation during the prenatal period. Electromagn Biol Med. 2025 Oct 22:1-10. doi: 10.1080/15368378.2025.2577318. (CE, GE, IU, ME, VO)

The aim of this study is to investigate the thyroid status of offspring exposed to prenatal 2.45 GHz radiofrequency radiation (RFR). In this study, which is the second phase of our previous study, the thyroids of rats exposed to prenatal 2.45 GHz RFR were examined one year after birth. The mothers of the offspring in the experimental group (n = 8) were exposed to 2.45 GHz RFR (whole-body specific absorption rate (SAR): 12 mW/kg; maximum point SAR: 25 mW/kg) 24 hours per day throughout pregnancy. The mothers in the sham group (n = 8) were kept under the same experimental conditions except for RFR exposure. The offspring in this study were not exposed to RFR after birth and continued their daily lives for one year. When the offspring reached one year of age, they were sacrificed and their thyroids were removed and evaluated. Mann-Whitney U and t tests were used for statistical analysis. Increases in fibrosis (p = 0.038), atypical thyrocytes (p = 0.002) and degenerated follicles (p = 0.007) and colloid reduction (p = 0.002) were found to be significant in the experimental group compared to the sham group. However, the increase in the percentage of apoptosis positive cells (p = 0.006) and H2A.X

antibody levels ($p = 0.007$) showed a statistically significant difference in the experimental group compared to the sham group. This study provides evidence that prenatal exposure to 2.45 GHz RFR can induce persistent histological changes, increase apoptosis, and cause DNA double-strand breaks in thyroid tissue observed one year after birth. These results underscore the importance of further long-term studies to assess developmental risks associated with prenatal RFR exposure.

Pandey N, Giri S. Melatonin attenuates radiofrequency radiation (900 MHz)-induced oxidative stress, DNA damage and cell cycle arrest in germ cells of male Swiss albino mice. Toxicol Ind Health 34(5):315-327, 2018.

Increasing male infertility of unknown aetiology can be associated with environmental factors. Extensive use of mobile phones has exposed the general population to unprecedented levels of radiofrequency radiations (RFRs) that may adversely affect male reproductive health. Therefore, the present study investigated the effect of RFR Global System for Mobile communication (GSM) type, 900 MHz and melatonin supplementation on germ cell development during spermatogenesis. Swiss albino mice were divided into four groups. One group received RFR exposure for 3 h twice/day for 35 days and the other group received the same exposure but with melatonin (N-acetyl-5-methoxytryptamine) (MEL; 5 mg/kg bw/day). Two other groups received only MEL or remain unexposed. Sperm head abnormality, total sperm count, biochemical assay for lipid peroxides, reduced glutathione, superoxide dismutase activity and testis histology were evaluated. Additionally, flow cytometric evaluation of germ cell subtypes and comet assay were performed in testis. Extensive DNA damage in germ cells of RFR-exposed animals along with arrest in pre-meiotic stages of spermatogenesis eventually leading to low sperm count and sperm head abnormalities were observed. Furthermore, biochemical assays revealed excess free radical generation resulting in histological and morphological changes in testis and germ cells morphology, respectively. However, these effects were either diminished or absent in RFR-exposed animals supplemented with melatonin. Hence, it can be concluded that melatonin inhibits pre-meiotic spermatogenesis arrest in male germ cells through its anti-oxidative potential and ability to improve DNA reparative pathways, leading to normal sperm count and sperm morphology in RFR-exposed animals.

Pandey, N., Giri, S., Das, S., Upadhaya, P. Radiofrequency radiation (900 MHz)-induced DNA damage and cell cycle arrest in testicular germ cells in swiss albino mice. Toxicol Ind Health. 33:33-384, 2017.

Even though there are contradictory reports regarding the cellular and molecular changes induced by mobile phone emitted radiofrequency radiation (RFR), the possibility of any biological effect cannot be ruled out. In view of a widespread and extensive use of mobile phones, this study evaluates alterations in male germ cell transformation kinetics following RFR exposure and after recovery. Swiss albino mice were exposed to RFR (900 MHz) for 4 h and 8 h duration per day for 35 days. One group of animals was terminated after the exposure period, while others were kept for an additional 35 days post-exposure. RFR exposure caused depolarization of mitochondrial membranes resulting in destabilized cellular redox homeostasis. Statistically significant increases in the damage index in germ cells and sperm head defects were

noted in RFR-exposed animals. Flow cytometric estimation of germ cell subtypes in mice testis revealed 2.5-fold increases in spermatogonial populations with significant decreases in spermatids. Almost fourfold reduction in spermatogonia to spermatid turnover (1C:2C) and three times reduction in primary spermatocyte to spermatid turnover (1C:4C) was found indicating arrest in the premeiotic stage of spermatogenesis, which resulted in loss of post-meiotic germ cells apparent from testis histology and low sperm count in RFR-exposed animals. Histological alterations such as sloughing of immature germ cells into the seminiferous tubule lumen, epithelium depletion and maturation arrest were also observed. However, all these changes showed recovery to varied degrees following the post-exposure period indicating that the adverse effects of RFR on mice germ cells are detrimental but reversible. To conclude, RFR exposure-induced oxidative stress causes DNA damage in germ cells, which alters cell cycle progression leading to low sperm count in mice.

Pavicić, I., Trosić, I., Sarolić, A. Comparison of 864 MHz and 935 MHz microwave radiation effects on cell culture. Arh Hig Rada Toksikol. 57:149-54, 2006.

The objective of this study was to compare the effects of 864 MHz and 935 MHz radiofrequency/microwave radiation on the ability of V79 cells to proliferate, form colonies and on their viability. For one, two and three hours, the cells were exposed to the 864 MHz field in a transversal electromagnetic mode cell (TEM) connected with amplifier and to the 935 MHz field in a gigahertz transversal electromagnetic mode cell (GTEM) equipped with a signal generator. The average specific absorption rate (SAR) was 0.08 W kg(-1) for the 864 MHz field and 0.12 W kg(-1) for the 935 MHz field. In comparison to the control cell samples, the growth curve of the 864 MHz irradiated cells showed a significant decrease after two-hour and three-hour exposure on the Day 3 after exposure. Likewise, cells exposed to 935 MHz microwaves for three hours showed a significant growth on Day 3 after exposure. The colony-forming ability and viability of cells exposed to 864 MHz and 935 MHz microwaves did not significantly differ from the matched controls. The applied RF/MW fields showed a similar effect on cell culture growth, colony-forming ability and viability of V79 cells.

Pelletier, A., Delanaud, S., Décima, P., Thuroczy, G., de Seze, R., Cerri, M., Bach, V., Libert, J.P., Loos, N. Effects of chronic exposure to radiofrequency electromagnetic fields on energy balance in developing rats. Environ Sci Pollut Res Int. 20:2735-2746, 2013.

The effects of radiofrequency electromagnetic fields (RF-EMF) on the control of body energy balance in developing organisms have not been studied, despite the involvement of energy status in vital physiological functions. We examined the effects of chronic RF-EMF exposure (900 MHz, 1 V m(-1)) on the main functions involved in body energy homeostasis (feeding behaviour, sleep and thermoregulatory processes). Thirteen juvenile male Wistar rats were exposed to continuous RF-EMF for 5 weeks at 24 °C of air temperature (T a) and compared with 11 non-exposed animals. Hence, at the beginning of the 6th week of exposure, the functions were recorded at T a of 24 °C and then at 31 °C. We showed that the frequency of rapid eye movement sleep episodes was greater in the RF-EMF-exposed group, independently of T a (+42.1 % at 24 °C and +31.6 % at 31 °C). The other effects of RF-EMF exposure on several sleep parameters were dependent on T a. At 31 °C, RF-EMF-exposed animals had a significantly lower subcutaneous tail temperature (-1.21 °C) than controls at all sleep stages; this suggested

peripheral vasoconstriction, which was confirmed in an experiment with the vasodilatator prazosin. Exposure to RF-EMF also increased daytime food intake (+0.22 g h(-1)). Most of the observed effects of RF-EMF exposure were dependent on T a. Exposure to RF-EMF appears to modify the functioning of vasomotor tone by acting peripherally through α-adrenoceptors. The elicited vasoconstriction may restrict body cooling, whereas energy intake increases. Our results show that RF-EMF exposure can induce energy-saving processes without strongly disturbing the overall sleep pattern.

Pérez-Castejón, C., Pérez-Bruzón, R.N., Llorente, M., Pes, N., Lacasa, C., Figols, T., Lahoz, M., Maestú, C., Vera-Gil, A., Del Moral, A., Azanza, M.J. Exposure to ELF-pulse modulated X band microwaves increases in vitro human astrocytoma cell proliferation. Histol Histopathol. 24: 1551-1561, 2009.

Common concern about the biological effects of electromagnetic fields (EMF) is increasing with the expansion of X-band microwaves (MW). The purpose of our work was to determine whether exposure to MW pulses in this range can induce toxic effects on human astrocytoma cells. Cultured astrocytoma cells (Clonetics line 1321N1) were submitted to 9.6 GHz carrier, 90% amplitude modulated by extremely low frequency (ELF)-EMF pulses inside a Gigahertz Transversal Electromagnetic Mode cell (GTEM-cell). Astrocytoma cultures were maintained inside a GTEM-incubator in standard culture conditions at 37+/-0.1 degrees C, 5% CO2, in a humidified atmosphere. Two experimental conditions were applied with field parameters respectively of: PW 100-120 ns; PRF 100-800 Hz; PRI 10-1.25 ms; power 0.34-0.60 mW; electric field strength 1.25-1.64 V/m; magnetic field peak amplitude 41.4-54.6 microOe. SAR was calculated to be 4.0 x 10-4 W/Kg. Astrocytoma samples were grown in a standard incubator. Reaching 70-80% confluence, cells were transferred to a GTEM-incubator. Experimental procedure included exposed human astrocytoma cells to MW for 15, 30, 60 min and 24 h and unexposed sham-control samples. Double blind method was applied. Our results showed that cytoskeleton proteins, cell morphology and viability were not modified. Statistically significant results showed increased cell proliferation rate under 24h MW exposure. Hsp-70 and Bcl-2 antiapoptotic proteins were observed in control and treated samples, while an increased expression of connexin 43 proteins was found in exposed samples. The implication of these results on increased proliferation is the subject of our current research.

Perov, S., Rubtsova, N., Balzano, Q. Effects of 171 MHz low-intensity electromagnetic field on glucocorticoid and mineral corticoid activity of the adrenal glands of rats. Bioelectromagnetics. 40:578-587, 2019.

A sub-acute electromagnetic field (EMF) biological effect study was carried out on rats exposed in the Transverse ElectroMagnetic exposure chamber at 171 MHz Continuous Wave (CW). The experiments involved three exposure levels (15, 25, and 35 V/m) for 15 days with triplicate parallel sham-exposed controls in each series. All exposure conditions were simulated for the evaluation of the electromagnetic energy distribution and specific absorption rate (SAR) in the rat phantoms. Studies have shown a biphasic biological response depending on time and absorbed electromagnetic energy. Under low SAR, approximately 0.006 W/kg, EMF exposure leads to the stimulation of adrenal gland activity. This process is accompanied by an initial increase of daily excretion of corticosterone and Na^+ , which is seen as a higher Na^+ /K^+ ratio,

followed by a decrease of these parameters over time. It is possible that EMF exposure causes a stress response in animals, which is seen as an increased adrenal activity.

Persson, B.R.R., Salford, L.G., Brun, A, Blood-brain barrier permeability in rats exposed to electromagnetic fields used in wireless communication. Wireless Network. 3:455-461, 1997.

Biological effects of radio frequency electromagnetic fields (EMF) on the blood-brain barrier (BBB) have been studied in Fischer 344 rats of both sexes. The rats were not anaesthetised during the exposure. All animals were sacrificed by perfusion–fixation of the brains under chloralhydrate anaesthesia after the exposure. The brains were perfused with saline for 3–4 minutes, and thereafter perfusion fixed with 4% formaldehyde for 5–6 minutes. Whole coronal sections of the brains were dehydrated and embedded in paraffin and sectioned at 5 µm. Albumin and fibrinogen were demonstrated immunohistochemically and classified as normal versus pathological leakage. In the present investigation we exposed male and female Fischer 344 rats in a Transverse Electromagnetic Transmission line chamber to microwaves of 915 MHz as continuous wave (CW) and pulse-modulated with different pulse power and at various time intervals. The CW-pulse power varied from 0.001 W to 10 W and the exposure time from 2 min to 960 min. In each experiment we exposed 4–6 rats with 2–4 controls randomly placed in excited and non-excited TEM-cells respectively. We have in total investigated 630 exposed rats at various modulation frequencies and 372 controls. The frequency of pathological rats is significantly increased ($p < 0.0001$) from 62/372 (ratio: 0.17 ± 0.02) for control rats to 244/630 (ratio: 0.39 ± 0.03) in all exposed rats. Grouping the exposed animals according to the level of specific absorbed energy (J/kg) give significant difference in all levels above 1.5 J/kg. The exposure was 915 MHz microwaves either pulse modulated (PW) at 217 Hz with 0.57 ms pulse width, at 50 Hz with 6.6 ms pulse width or continuous wave (CW). The frequency of pathological rats (0.17) among controls in the various groups is not significantly different. The frequency of pathological rats was 170/481 (0.35 ± 0.03) among rats exposed to pulse modulated (PW) and 74/149 (0.50 ±0.07) among rats exposed to continuous wave exposure (CW). These results are both highly significantly different to their corresponding controls ($p <0.0001$) and the frequency of pathological rats after exposure to pulsed radiation (PW) is significantly less ($p < 0.002$) than after exposure to continuous radiation (CW).

Phillips, J.L., Ivaschuk, O., Ishida-Jones, T., Jones, R.A., Campbell-Beachler, M., Haggren, W. DNA damage in Molt-4 T- lymphoblastoid cells exposed to cellular telephone radiofrequency fields *in vitro.* Bioelectrochem. Bioenerg. 45:103–110, 1998.

Molt-4 T-lymphoblastoid cells have been exposed to pulsed signals at cellular telephone frequencies of 813.5625 MHz (iDEN® signal) and 836.55 MHz (TDMA signal). These studies were performed at low SAR (average=2.4 and 24 $\mu W\ g^{-1}$ for iDEN® and 2.6 and 26 $\mu W\ g^{-1}$ for TDMA) in studies designed to look for athermal RF effects. The alkaline comet, or single cell gel electrophoresis, assay was employed to measure DNA single-strand breaks in cell cultures exposed to the radiofrequency (RF) signal as compared to concurrent sham-exposed cultures. Tail moment and comet extent were calculated as indicators of DNA damage. Statistical differences in the distribution of values for tail moment and comet extent between exposed and control cell cultures were evaluated with the Kolmogorov–Smirnoff distribution test. Data points for all experiments of each exposure condition

were pooled and analyzed as single groups. It was found that: 1) exposure of cells to the iDEN® signal at an SAR of 2.4 μW g^{-1} for 2 h or 21 h significantly decreased DNA damage; 2) exposure of cells to the TDMA signal at an SAR of 2.6 μW g^{-1} for 2 h and 21 h significantly decreased DNA damage; 3) exposure of cells to the iDEN® signal at an SAR of 24 μW g^{-1} for 2 h and 21 h significantly increased DNA damage; 4) exposure of cells to the TDMA signal at an SAR of 26 μW g^{-1} for 2 h significantly decreased DNA damage. The data indicate a need to study the effects of exposure to RF signals on direct DNA damage and on the rate at which DNA damage is repaired.

Piccinetti, C.C., De Leo, A., Cosoli, G., Scalise, L., Randazzo, B., Cerri, G., Olivotto, I. Measurement of the 100 MHz EMF radiation in vivo effects on zebrafish D. rerio embryonic development: A multidisciplinary study. Ecotoxicol Environ Saf. 154:268-279, 2018.

The augmented exposure of both environment and human being to electromagnetic waves and the concomitant lack of an unequivocal knowledge about biological consequences of these radiations, raised public interest on electromagnetic pollution. In this context, the present study aims to evaluate the biological effects on zebrafish (ZF) embryos of 100 MHz radiofrequency electromagnetic field (RF-EMF) exposure through a multidisciplinary protocol. Because of the shared synteny between human and ZF genomes that validated its use in biomedical research, toxicology and developmental biology studies, ZF was here selected as experimental model and a measurement protocol and biological analyses have been set up to clearly discriminate between RF-EMF biological and thermal effects. The results showed that a 100 MHz EMF was able to affect ZF embryonic development, from 24 to 72 h post fertilization (hpf) in all the analyzed pathways. Particularly, at the 48 hpf stage, a reduced growth, an increased transcription of oxidative stress genes, the onset of apoptotic/autophagic processes and a modification in cholesterol metabolism were detected. ZF embryos faced stress induced by EMF radiation by triggering detoxification mechanisms and at 72 hpf they partially recovered from stress reaching the hatching time in a comparable way respect to the control group. Data here obtained showed unequivocally the in vivo effects of RF-EMF on an animal model, excluding thermal outcomes and thus represents the starting point for more comprehensive studies on dose response effects of electromagnetic fields radiations consequences.

Porcher A, Girard S, Bonnet P, Rouveure R, Guérin V, Paladian F, Vian A. Non thermal 2.45 GHz electromagnetic exposure causes rapid changes in Arabidopsis thaliana metabolism. J Plant Physiol 286:153999, 2023.

Numerous studies report different types of responses following exposure of plants to high frequency electromagnetic fields (HF-EMF). While this phenomenon is related to tissue heating in animals, the situation is much less straightforward in plants where metabolic changes seem to occur without tissue temperature increase. We have set up an exposure system allowing reliable measurements of tissue heating (using a reflectometric probe and thermal imaging) after a long exposure (30 min) to an electromagnetic field of 2.45 GHz transmitted through a horn antenna (about 100 V m-1 at the plant level). We did not observe any heating of the tissues, but we detected rapid increases (60 min) in the accumulation of transcripts of stress-related genes (TCH1 and ZAT12 transcription factor) or involved in ROS metabolism (RBOHF and APX1). At the same time, the amounts of hydrogen peroxide and dehydroascorbic acid increased while glutathione (reduced and oxidized forms), ascorbic acid, and lipid peroxidation remained stable.

Therefore, our results unambiguously show that molecular and biochemical responses occur rapidly (within 60min) in plants after exposure to an electromagnetic field, in absence of tissue heating.

Postaci, I., Coskun, O., Senol, N., Aslankoc, R., Comlekci, S. The physiopathological effects of quercetin on oxidative stress in radiation of 4.5 g mobile phone exposed liver tissue of rat. Bratisl Lek Listy. 119:481-489, 2018.

Objective: The study was aimed to evaluate the physiopathological consideration of the effects of electromagnetic field (EMF) from the radiation of 4.5 G mobile phones on the liver tissue of rats and quercetin (Qu) applied as an antioxidant for reducing these effects. **Methods:** Male Wistar-Albino rats were divided into four groups with 8 rats in each group. Group 1 (control group), Group 2 (sham group), Group 3 (EMF group) and Group 4 (EMF + Qu). From the animals sacrificed at the end of the 30th day; liver tissues were taken for histopathological and immunohistochemical examinations. **Results:** In the liver tissue of the electromagnetic field group; dilatation of sinusitis was determined to be higher than in the sham group. It was concluded that the concentration of caspase-3 and TNF-α immunopositive cells was in the EMF group (+3) level and also the immunostaining was stronger, it caused an increase in malondialdehyde level, the difference between the groups was statistically significant, in terms of superoxide dismutase, catalase activities, the difference was not significant. **Conclusion:** It was determined that 2600 MHz EMF exposure caused damage to the liver, 100 mg/kg/day quercetin was not sufficient to prevent this damage (Tab. 5, Fig. 15, Ref. 27).

Postacı Karaman İ, Coşkun Ö, Şenol N, Şahin U, Çömlekçi S. Protective Effects of Ginseng on the Blood–Brain Barrier in Rats Exposed to 2600 MHz Radiofrequency Radiation. *Applied Sciences*. 16(8):4012, 2026.

Radiofrequency radiation (RFR) exposure is higher in the structures surrounding the ears and head. Moreover, the brain is the organ most vulnerable to microwave radiation, exhibiting earlier and more severe mitochondrial damage compared to other tissues. The present study investigated the impact of 2600 MHz RFR on the blood–brain barrier (BBB) through immunohistochemical, genetic, and biochemical analyses and explored the potential protective role of ginseng. The animals in the study were randomly assigned to five groups (n = 8 per group): control, sham, ginseng, 2600 MHz RFR, and 2600 MHz RFR + ginseng. The RFR groups were exposed to RFR for 1 h day^{-1} for 30 days. Ginseng was applied every day (150 mg/kg/day) by gavage for 30 days. Histopathological examination of the 2600 MHz RFR group revealed degenerative changes, vacuolization, vascular dilatation, and mild edema, particularly in cortical neurons. These alterations appeared reduced in the sham and 2600 MHz RFR + ginseng groups. The immunohistochemical findings indicated moderate damage in the RFR group, whereas a statistically significant decrease was observed in the ginseng-treated groups ($p < 0.05$). Overall, the findings suggest that 2600 MHz RFR may be associated with increased apoptotic activity and ginseng may exert a protective effect.

Pyrpasopoulou, A., Kotoula, V., Cheva, A., Hytiroglou, P., Nikolakaki, E., Magras, I.N., Xenos, T.D., Tsiboukis, T.D., Karkavelas, G. Bone morphogenetic protein expression in newborn rat kidneys after prenatal exposure to radiofrequency radiation.

Bioelectromagnetics. 25:216-227, 2004.

Effects of nonthermal radiofrequency radiation (RFR) of the global system of mobile communication (GSM) cellular phones have been as yet mostly studied at the molecular level in the context of cellular stress and proliferation, as well as neurotransmitter production and localization. In this study, a simulation model was designed for the exposure of pregnant rats to pulsed GSM-like RFR (9.4 GHz), based on the different resonant frequencies of man and rat. The power density applied was 5 microW/cm2, in order to avoid thermal electromagnetic effects as much as possible. Pregnant rats were exposed to RFR during days 1-3 postcoitum (p.c.) (embryogenesis, pre-implantation) and days 4-7 p.c. (early organogenesis, peri-implantation). Relative expression and localization of bone morphogenetic proteins (BMP) and their receptors (BMPR), members of a molecular family currently considered as major endocrine and autocrine morphogens and known to be involved in renal development, were investigated in newborn kidneys from RFR exposed and sham irradiated (control) rats. Semi-quantitative duplex RT-PCR for BMP-4, -7, BMPR-IA, -IB, and -II showed increased BMP-4 and BMPR-IA, and decreased BMPR-II relative expression in newborn kidneys. These changes were statistically significant for BMP-4, BMPR-IA, and -II after exposure on days 1-3 p.c. ($P < .001$ each), and for BMP-4 and BMPR-IA after exposure on days 4-7 p.c. ($P < .001$ and $P = .005$, respectively). Immunohistochemistry and in situ hybridization (ISH) showed aberrant expression and localization of these molecules at the histological level. Our findings suggest that GSM-like RFR interferes with gene expression during early gestation and results in aberrations of BMP expression in the newborn. These molecular changes do not appear to affect renal organogenesis and may reflect a delay in the development of this organ. The differences of relative BMP expression after different time periods of exposure indicate the importance of timing for GSM-like RFR effects on embryonic development.

Qin F, Zhang J, Cao H, Guo W, Chen L, Shen O, Sun J, Yi C, Li J, Wang J, Tong J. Circadian alterations of reproductive functional markers in male rats exposed to 1800-MHz radiofrequency field. Chronobiol Int. 3191):123-133, 2014.

In this study, we explored the circadian effects of daily radiofrequency field (RF) exposure on reproductive functional markers in adult male Sprague-Dawley rats. Animals in circadian rhythm (as indicated by melatonin measurements), were divided into several groups and exposed to 1800 MHz RF at 205 μw/cm^2 power density (specific absorption rate 0.0405 W/kg) for 2 h/day for 32 days at different zeitgeber time (ZT) points, namely, ZT0, ZT4, ZT8, ZT12, ZT16 and ZT20. Sham-exposed animals were used as controls in the study. From each rat, testicular and epididymis tissues were collected and assessed for testosterone levels, daily sperm production and sperm motility, testis marker enzymes γ-GT and ACP, cytochrome P450 side-chain cleavage (p450cc) mRNA expression, and steroidogenic acute regulatory protein (StAR) mRNA expression. Via these measurements, we confirmed the existence of circadian rhythms in sham-exposed animals. However, rats exposed to RF exhibited a disruption of circadian rhythms, decreased testosterone levels, lower daily sperm production and sperm motility, down-regulated activity of γ-GT and ACP, as well as altered mRNA expression of cytochrome P450 and StAR. All of these observations were more pronounced when rats were exposed to RF at ZT0. Thus, our findings indicate potential adverse effects of RF exposure on male reproductive functional markers, in terms of both the daily overall levels as well as the circadian rhythmicity.

Qin F, Shen T, Cao H, Qian J, Zou D, Ye M, Pei H. CeO_2NPs relieve radiofrequency radiation, improve testosterone synthesis, and clock gene expression in Leydig cells by enhancing antioxidation. Int J Nanomedicine. 14:4601-4611, 2019.

Introduction: The ratio of Ce^{3+}/Ce^{4+} in their structure confers unique functions on cerium oxide nanoparticles (CeO_2NPs) containing rare earth elements in scavenging free radicals and protecting against oxidative damage. The potential of CeO_2NPs to protect testosterone synthesis in primary mouse Leydig cells during exposure to 1,800 MHz radiofrequency (RF) radiation was examined in vitro. **Methods:** Leydig cells were treated with different concentrations of CeO_2NPs to identify the optimum concentration for cell proliferation. The cells were pretreated with the optimum dose of CeO_2NPs for 24 hrs and then exposed to 1,800 MHz RF at a power density of 200.27 $\mu W/cm^2$ (specific absorption rate (SAR), 0.116 W/kg) for 1 hr, 2 hrs, or 4 hrs. The medium was used to measure the testosterone concentration. The cells were collected to determine the antioxidant indices (catalase [CAT], malondialdehyde [MDA], and total antioxidant capacity [T-AOC]), and the mRNA expression of the testosterone synthase genes (*Star, Cyp11a1*, and *Hsd-3β*) and clock genes (*Clock, Bmal1*, and *Rorα*). **Results:** Our preliminary result showed that 128 μg/mL CeO_2NPs was the optimum dose for cell proliferation. Cells exposed to RF alone showed reduced levels of testosterone, T-AOC, and CAT activities, increased MDA content, and the downregulated genes expression of *Star, Cyp11a1, Hsd-3β, Clock, Bmal1*, and *Rorα*. Pretreatment of the cells with 128 μg/mL CeO_2NPs for 24 hrs followed by RF exposure significantly increased testosterone synthesis, upregulated the expression of the testosterone synthase and clock genes, and increased the resistance to oxidative damage in Leydig cells compared with those in cells exposed to RF alone. **Conclusion:** Exposure to 1,800 MHz RF had adverse effects on testosterone synthesis, antioxidant levels, and clock gene expression in primary Leydig cells. Pretreatment with CeO_2NPs prevented the adverse effects on testosterone synthesis induced by RF exposure by regulating their antioxidant capacity and clock gene expression in vitro. Further studies of the mechanism underlying the protective function of CeO_2NPs against RF in the male reproductive system are required.

Rafati, A., Rahimi, S., Talebi, A., Soleimani, A., Haghani, M., Mortazavi, S.M. Exposure to radiofrequency radiation emitted from common mobile phone jammers alters the pattern of muscle contractions: an animal model study. J Biomed Phys Eng. 5:133-142, 2015.

Introduction: The rapid growth of wireless communication technologies has caused public concerns regarding the biological effects of electromagnetic radiations on human health. Some early reports indicated a wide variety of non-thermal effects of electromagnetic radiation on amphibians such as the alterations of the pattern of muscle extractions. This study is aimed at investigating the effects of exposure to radiofrequency (RF) radiation emitted from mobile phone jammers on the pulse height of contractions, the time interval between two subsequent contractions and the latency period of frog's isolated gastrocnemius muscle after stimulation with single square pulses of 1V (1 Hz).**Materials and methods:** Frogs were kept in plastic containers in a room. Animals in the jammer group were exposed to radiofrequency (RF) radiation emitted from a common Jammer at a distance of 1m from the jammer's antenna for 2 hours while the control frogs were only sham exposed. Then animals were sacrificed and isolated gastrocnemius

muscles were exposed to on/off jammer radiation for 3 subsequent 10 minute intervals. Isolated gastrocnemius muscles were attached to the force transducer with a string. Using a PowerLab device (26-T), the pattern of muscular contractions was monitored after applying single square pulses of 1V (1 Hz) as stimuli. **Results:** The findings of this study showed that the pulse height of muscle contractions could not be affected by the exposure to electromagnetic fields. However, the latency period was effectively altered in RF-exposed samples. However, none of the experiments could show an alteration in the time interval between two subsequent contractions after exposure to electromagnetic fields. **Conclusion:** These findings support early reports which indicated a wide variety of non-thermal effects of electromagnetic radiation on amphibians including the effects on the pattern of muscle extractions.

Sagioglou NE, Manta AK, Giannarakis IK, Skouroliakou AS, Margaritis LH. Apoptotic cell death during Drosophila oogenesis is differentially increased by electromagnetic radiation depending on modulation, intensity and duration of exposure. Electromagn Biol Med. 35:40-53, 2016.

Present generations are being repeatedly exposed to different types and doses of non-ionizing radiation (NIR) from wireless technologies (FM radio, TETRA and TV stations, GSM and UMTS phones/base stations, Wi-Fi networks, DECT phones). Although there is controversy on the published data regarding the non-thermal effects of NIR, studies have convincingly demonstrated bioeffects. Their results indicate that modulation, intensity, exposure duration and model system are important factors determining the biological response to irradiation. Attempting to address the dependence of NIR bioeffectiveness on these factors, apoptosis in the model biological system Drosophila melanogaster was studied under different exposure protocols. A signal generator was used operating alternatively under Continuous Wave (CW) or Frequency Modulation (FM) emission modes, at three power output values (10 dB, 0, -10 dB), under four carrier frequencies (100, 395, 682, 900 MHz). Newly emerged flies were exposed either acutely (6 min or 60 min on the 6th day), or repeatedly (6 min or 60 min daily for the first 6 days of their life). All exposure protocols resulted in an increase of apoptotic cell death (ACD) observed in egg chambers, even at very low electric field strengths. FM waves seem to have a stronger effect in ACD than continuous waves. Regarding intensity and temporal exposure pattern, EMF-biological tissue interaction is not linear in response. Intensity threshold for the induction of biological effects depends on frequency, modulation and temporal exposure pattern with unknown so far mechanisms. Given this complexity, translating such experimental data into possible human exposure guidelines is yet arbitrary.

Salford, L.G., Brun, A.R., Eberhardt, J.L., Malmgren, L., Persson, B.R.R. Nerve cell damage in mammalian brain after exposure to microwaves from GSM mobile phones. Environ Health Persp. 111:881-883, 2003.

The possible risks of radio-frequency electromagnetic fields for the human body is a growing concern for our society. We have previously shown that weak pulsed microwaves give rise to a significant leakage of albumin through the blood-brain barrier. In this study we investigated whether a pathologic leakage across the blood-brain barrier might be combined with damage to the neurons. Three groups each of eight rats were exposed for 2 hr to Global System for Mobile

Communications (GSM) mobile phone electromagnetic fields of different strengths. We found highly significant ($p < 0.002$) evidence for neuronal damage in the cortex, hippocampus, and basal ganglia in the brains of exposed rats.

Sangun O, Dundar B, Darici H, Comlekci S, Doguc DK, Celik S. The effects of long-term exposure to a 2450 MHz electromagnetic field on growth and pubertal development in female Wistar rats. Electromagn Biol Med. 34(1):63-71, 2015.

The aim of this study was to investigate the effects of a 2450 MHz electromagnetic field (EMF) (wireless internet frequency) on the growth and development of female Wistar rats. The study was conducted on three groups of rats. The prenatal and postnatal groups were exposed to EMF 1 h/day beginning from intrauterine and postnatal periods, respectively. The third group was the sham-exposed group. Growth, nutrition and vaginal opening (VO) were regularly monitored. Serum and tissue specimens were collected at puberty. Histological examinations, total antioxidant status (TAS), total oxidant status (TOS) and oxidative stress index (OSI) measurements in ovary and brain tissues and also immunohistochemical staining of the hypothalamus were performed besides the determination of serum FSH, LH, E2 and IGF-1 values. Birth masses of the groups were similar ($p > 0.05$). Mass gain per day was significantly lower and the puberty was significantly later in the prenatal group. Brain and ovary TOS and OSI values in the prenatal group were significantly increased ($p < 0.05$) compared to the control group. Serum LH levels of the prenatal and postnatal groups were increased, although serum FSH, and E2 values did not differ among the groups ($p > 0.05$). Histological examinations of the specimens revealed no statistically significant difference between the groups ($p > 0.05$). Exposure to 2450 MHz EMF, particularly in the prenatal period, resulted in postnatal growth restriction and delayed puberty in female Wistar rats. Increased TOS and OSI values in the brain and ovary tissues can be interpreted as a sign of chronic stress induced by EMF. This is the first longitudinal study which investigates the effects of EMF induced by wireless internet on pubertal development beside growth.

Sannino A, Zeni O, Romeo S, Massa R, Gialanella G, Grossi G, Manti L, Vijayalaxmi, Scarfi MR. Adaptive response in human blood lymphocytes exposed to non-ionizing radiofrequency fields: resistance to ionizing radiation-induced damage. J Radiat Res. 55: 210-217, 2014.

The aim of this preliminary investigation was to assess whether human peripheral blood lymphocytes which have been pre-exposed to non-ionizing radiofrequency fields exhibit an adaptive response (AR) by resisting the induction of genetic damage from subsequent exposure to ionizing radiation. Peripheral blood lymphocytes from four healthy donors were stimulated with phytohemagglutinin for 24 h and then exposed for 20 h to 1950 MHz radiofrequency fields (RF, adaptive dose, AD) at an average specific absorption rate of 0.3 W/kg. At 48 h, the cells were subjected to a challenge dose (CD) of 1.0 or 1.5 Gy X-irradiation (XR, challenge dose, CD). After a 72 h total culture period, cells were collected to examine the incidence of micronuclei (MN). There was a significant decrease in the number of MN in lymphocytes exposed to RF + XR (AD + CD) as compared with those subjected to XR alone (CD). These observations thus suggested a RF-induced AR and induction of resistance to subsequent damage from XR. There was variability between the donors in RF-induced AR. The data reported in our

earlier investigations also indicated a similar induction of AR in human blood lymphocytes that had been pre-exposed to RF (AD) and subsequently treated with a chemical mutagen, mitomycin C (CD). Since XR and mitomycin-C induce different kinds of lesions in cellular DNA, further studies are required to understand the mechanism(s) involved in the RF-induced adaptive response.

Sarimov, R., Malmgren, L.O.G., Markova, E., Persson, B.R.R., Belyaev, I.Y. Nonthermal GSM microwaves affect chromatin conformation in human lymphocytes similar to heat shock. IEEE Trans Plasma Sci. 32:1600-1608, 2004.

Here we investigated whether microwaves (MWs) of Global System for Mobile Communication (GSM) induce changes in chromatin conformation in human lymphocytes. Effects of MWs were studied at different frequencies in the range of 895-915 MHz in experiments with lymphocytes from seven healthy persons. Exposure was performed in transverse electromagnetic transmission line cell (TEM-cell) using a GSM test-mobile phone. All standard modulations included 2 W output power in the pulses, specific absorbed rate (SAR) being 5.4 mW/kg. Changes in chromatin conformation, which are indicative of stress response and genotoxic effects, were measured by the method of anomalous viscosity time dependencies (AVTD). Heat shock and treatment with the genotoxic agent camptothecin, were used as positive controls. 30-min exposure to MWs at 900 and 905 MHz resulted in statistically significant condensation of chromatin in lymphocytes from 1 of 3 tested donors. This condensation was similar to effects of heat shock within the temperature window of 40/spl deg/C-44/spl deg/C. Analysis of pooled data from all donors showed statistically significant effect of 30-min exposure to MWs. Stronger effects of MWs was found following 1-h exposure. In replicated experiments, cells from four out of five donors responded to 905 MHz. Responses to 915 MHz were observed in cells from 1 out of 5 donors, $p<0.002$. Dependent on donor, condensation, 3 donors, or decondensation, 1 donor, of chromatin was found in response to 1-h exposure. Analysis of pooled data from all donors showed statistically significant effect of 1-h exposure to MWs. In cells from one donor, this effect was frequency-dependent ($p<0.01$). Effects of MWs correlated statistically significantly with effects of heat shock and initial state of chromatin before exposure. MWs at 895 and 915 MHz affected chromatin conformation in transformed lymphocytes. The conclusion-GSM microwaves under specific conditions of exposure affected human lymphocytes similar to stress response. The data suggested that the MW effects differ at various GSM frequencies and vary between donors.

Schwarz, C., Kratochvil, E., Pilger, A., Kuster, N., Adlkofer, F., Rüdiger, H.W. Radiofrequency electromagnetic fields (UMTS, 1,950 MHz) induce genotoxic effects in vitro in human fibroblasts but not in lymphocytes. Int Arch Occup Environ Health. 81:755-767, 2008.

Objective: Universal Mobile Telecommunication System (UMTS) was recently introduced as the third generation mobile communication standard in Europe. This was done without any information on biological effects and genotoxic properties of these particular high-frequency electromagnetic fields. This is discomforting, because genotoxic effects of the second generation standard Global System for Mobile Communication have been reported after exposure of human cells in vitro. **Methods:** Human cultured fibroblasts of three different donors and three different

short-term human lymphocyte cultures were exposed to 1,950 MHz UMTS below the specific absorption rate (SAR) safety limit of 2 W/kg. The alkaline comet assay and the micronucleus assay were used to ascertain dose and time-dependent genotoxic effects. Five hundred cells per slide were visually evaluated in the comet assay and comet tail factor (CTF) was calculated. In the micronucleus assay 1,000 binucleated cells were evaluated per assay. The origin of the micronuclei was determined by fluorescence labeled anticentromere antibodies. All evaluations were performed under blinded conditions. **Results:** UMTS exposure increased the CTF and induced centromere-negative micronuclei (MN) in human cultured fibroblasts in a dose and time-dependent way. Incubation for 24 h at a SAR of 0.05 W/kg generated a statistically significant rise in both CTF and MN (P = 0.02). At a SAR of 0.1 W/kg the CTF was significantly increased after 8 h of incubation (P = 0.02), the number of MN after 12 h (P = 0.02). No UMTS effect was obtained with lymphocytes, either unstimulated or stimulated with Phytohemagglutinin. **Conclusion:** UMTS exposure may cause genetic alterations in some but not in all human cells in vitro.

Schwartz, J.L., House, D.E., Mealing, G.A, Exposure of frog hearts to CW or amplitude-modulated VHF fields: selective efflux of calcium ions at 16 Hz. Bioelectromagnetics. 11:349-358, 1990.

Isolated frog hearts were exposed for 30-min periods in a Crawford cell to a 240-MHz electromagnetic field, either continuous-wave or sinusoidally modulated at 0.5 or 16 Hz. Radiolabeled with calcium (45Ca), the hearts were observed for movement of Ca2+ at calculated SARs of 0.15, 0.24, 0.30, 0.36, 1.50, or 3.00 mW/kg. Neither CW radiation nor radiation at 0.5 Hz, which is close to the beating frequency of the frog's heart, affected movement of calcium ions. When the VHF field was modulated at 16 Hz, a field-intensity-dependent change in the efflux of calcium ions was observed. Relative to control values, ionic effluxes increased by about 18% at 0.3 mW/kg (P less than .01) and by 21% at 0.15 mW/kg (P less than .05), but movement of ions did not change significantly at other rates of energy deposition. These data indicate that the intact myocardium of the frog, akin to brain tissue of neonatal chicken, exhibits movement of calcium ions in response to a weak VHF field that is modulated at 16 Hz.

Seewooruttun C, Bouguila B, Corona A, Delanaud S, Bodin R, Bach V, Desailloud R, Pelletier A. 5G Radiofrequency Exposure Reduces *PRDM16* and *C/EBP β* mRNA Expression, Two Key Biomarkers for Brown Adipogenesis. Int J Mol Sci. 26(6):2792, 2025.

The widespread use of wireless technologies has raised public health concerns about the biological effects of radiofrequency (RF) exposure. Children have a higher specific absorption rate (SAR) of radiation energy compared to adults. Furthermore, brown adipose tissue (BAT) is more prevalent in infants and tends to decrease with age. Previous animal studies demonstrated a cold sensation in rats exposed to 900 MHz (second generation, 2G). UCP1-dependent thermogenesis and BAT hyperplasia are two fundamental adaptive mechanisms initiated in response to cold. This study investigated the impact of short-term exposure to 2G and fifth generation (5G) on key thermogenic and adipogenic markers related to these mechanisms while considering age and exposure duration. Juvenile and young adult Wistar rats were randomized into three subgroups: a 5G group (3.5 GHz), 2G group (900 MHz), and a control group (SHAM). They were exposed to their respective continuous-wave RF signals for 1 or 2 weeks at an

intensity of 1.5 V/m, with two exposure sessions of 1 h per day. After the exposure period, a RT-qPCR was carried out to evaluate the genetic markers involved in BAT thermogenesis and adipogenesis. Two adipogenic biomarkers were affected; a fold change reduction of 49% and 32% was detected for *PRDM16* ($p = 0.016$) and *C/EBP β* ($p = 0.0002$), respectively, after 5G exposure, regardless of age and exposure duration. No significant RF effect was found on UCP1-dependent thermogenesis at a transcriptional level. These findings suggest that exposure to a 5G radiofrequency may partially disrupt brown adipocyte differentiation and thermogenic function by downregulating *PRDM16* and *C/EBP β*, possibly leading to higher cold sensitivity.

Sefidbakht, Y., Moosavi-Movahedi, A.A., Hosseinkhani, S., Khodagholi, F., Torkzadeh-Mahani, M., Foolad, F., Faraji-Dana, R. Effects of 940 MHz EMF on bioluminescence and oxidative response of stable luciferase producing HEK cells. Photochem Photobiol Sci. 13:1082-1092, 2014.

The effects of mobile phone frequency electromagnetic field (RF-EMF, 940 MHz) on a stable cell line (HEK293T) harbouring the firefly luciferase gene were evaluated. A waveguide exposure system with 1 W input power provided the mean specific absorption rate of ≈0.09 W kg(-1) in 35 mm Petri dishes. The effects of exposure duration (15, 30, 45, 60 and 90 min) on luciferase activity and oxidative response elements were investigated. Endogenous luciferase activity was reduced after 30 and 45 min of continuous exposure, while after 60 min, the exposed cell lysate showed higher luciferase activity compared with the non-exposed control. Reactive oxygen species (ROS) generation was highest in the 30 min exposed cells as studied by 2',7'-dichlorodihydrofluorescein diacetate (DCFH-DA) fluorescence. The observed boost in ROS was then followed by a sharp rise in catalase (CAT) and superoxide dismutase (SOD) activity and elevation of glutathione (GSH) during the 45 min exposure. Decrease in lipid peroxidation (malondialdehyde, MDA) was meaningful for the 45 and 60 min exposed cells. Therefore, it appears that an increase in the activity of luciferase after 60 min of continuous exposure could be associated with a decrease in ROS level caused by activation of the oxidative response. This ability in cells to overcome oxidative stress and compensate the luciferase activity could also be responsible for the adaptive response mechanism detected in ionizing radiation studies with RF-EMF pre-treatments.

Sepehrimanesh M, Saeb M, Nazifi S, Kazemipour N, Jelodar G, Saeb S. Impact of 900 MHz electromagnetic field exposure on main male reproductive hormone levels: a Rattus norvegicus model. Int J Biometeorol. 58(7):1657-1663, 2014a.

This work analyzes the effects of radiofrequency-electromagnetic field (RF-EMF) exposure on the reproductive system of male rats, assessed by measuring circulating levels of FSH, LH, inhibin B, activin B, prolactin, and testosterone. Twenty adult male Sprague-Dawley rats (180 ± 10 g) were exposed to 900 MHz RF-EMF in four equal separated groups. The duration of exposure was 1, 2, and 4 h/day over a period of 30 days and sham-exposed animals were kept under the same environmental conditions as the exposed group except with no RF-EMF exposure. Before the exposure, at 15 and 30 days of exposure, determination of the above mentioned hormone levels was performed using ELISA. At the end of the experiment, FSH and LH values of the long time exposure (LTE) group were significantly higher than the sham-exposed group ($p < 0.05$). Serum activin B and prolactin in the LTE group showed significant

increase and inhibin B showed significant decrease than sham and short time exposed (STE) groups after 30 days RF-EMF exposure ($p < 0.05$). Also, a significant decrease in serum testosterone levels in the LTE group was found compared to short and moderate time exposed (MTE) groups after 30 days RF-EMF exposure ($p < 0.05$). Results suggest that reproductive hormone levels are disturbed as a result of RF-EMF exposure and it may possibly affect reproductive functions. However, testosterone and inhibin B concentrations as a fertility marker and spermatogenesis were decreased significantly.

Sepehrimanesh M, Kazemipour N, Saeb M, Nazifi S. Analysis of rat testicular proteome following 30-days exposure to 900 MHz electromagnetic field radiation. Electrophoresis.35(23):3331-3338, 2014b.

The use of electromagnetic field (EMF) generating apparatuses such as cell phones is increasing, and has caused an interest in the investigations of its effects on human health. We analyzed proteome in preparations from the whole testis in adult male Sprague-Dawley rats exposed for 1, 2 or 4 h/d for 30 consecutive days to 900 MHz EMF radiation, simulating a range of possible human cell phone use. Subjects were sacrificed immediately after the end of the experiment and testes fractions were solubilized and separated via high resolution 2-dimensional electrophoresis, and gel patterns were scanned, digitized and processed. Thirteen of the proteins which found only in sham or in exposure groups were identified by MALDI-TOF/TOF-MS. Among them, heat shock proteins, superoxide dismutase, peroxiredoxin-1 and other proteins related to misfolding of proteins and/or stress were identified. These results demonstrate significant effects of radio-frequency modulated electromagnetic fields (RF-EMF) exposure on proteome, particularly in protein species in the rodent testis, and suggest that a 30 d exposure to EMF radiation induces non-thermal stress in testicular tissue. The functional implication of the identified proteins was discussed.

Sepehrimanesh M, Kazemipour N, Saeb M, Nazifi S, Davis DL. Proteomic analysis of continuous 900-MHz radiofrequency electromagnetic field exposure in testicular tissue: a rat model of human cell phone exposure. Environ Sci Pollut Res Int. 24(15):13666-13673, 2017.

Although cell phones have been used worldwide, some adverse and toxic effects were reported for this communication technology apparatus. To analyze in vivo effects of exposure to radiofrequency-electromagnetic field (RF-EMF) on protein expression in rat testicular proteome, 20 Sprague-Dawley rats were exposed to 900 MHz RF-EMF for 0, 1, 2, or 4 h/day for 30 consecutive days. Protein content of rat testes was separated by high-resolution two-dimensional electrophoresis using immobilized pH gradient (pI 4-7, 7 cm) and 12% acrylamide and identified by MALDI-TOF/TOF-MS. Two protein spots were found differentially overexpressed ($P < 0.05$) in intensity and volume with induction factors 1.7 times greater after RF-EMF exposure. After 4 h of daily exposure for 30 consecutive days, ATP synthase beta subunit (ASBS) and hypoxia up-regulated protein 1 precursor (HYOU1) were found to be significantly up-regulated. These proteins affect signaling pathways in rat testes and spermatogenesis and play a critical role in protein folding and secretion in the endoplasmic reticulum. Our results indicate that exposure to RF-EMF produces increases in testicular proteins in adults that are related to carcinogenic risk and reproductive damage. In light of the widespread practice of men carrying phones in their

pockets near their gonads, where exposures can exceed as-tested guidelines, further study of these effects should be a high priority.

Shahin, S., Singh, V.P., Shukla, R.K., Dhawan, A., Gangwar, R.K., Singh, S.P., Chaturvedi, C.M.. 2.45 GHz microwave irradiation-induced oxidative stress affects implantation or pregnancy in mice, Mus musculus. Appl Biochem Biotechnol. 169:1727-1751, 2013.

The present experiment was designed to study the 2.45 GHz low-level microwave (MW) irradiation-induced stress response and its effect on implantation or pregnancy in female mice. Twelve-week-old mice were exposed to MW radiation (continuous wave for 2 h/day for 45 days, frequency 2.45 GHz, power density=0.033549 mW/cm(2), and specific absorption rate=0.023023 W/kg). At the end of a total of 45 days of exposure, mice were sacrificed, implantation sites were monitored, blood was processed to study stress parameters (hemoglobin, RBC and WBC count, and neutrophil/lymphocyte (N/L) ratio), the brain was processed for comet assay, and plasma was used for nitric oxide (NO), progesterone and estradiol estimation. Reactive oxygen species (ROS) and the activities of ROS-scavenging enzymes- superoxide dismutase, catalase, and glutathione peroxidase-were determined in the liver, kidney and ovary. We observed that implantation sites were affected significantly in MW-irradiated mice as compared to control. Further, in addition to a significant increase in ROS, hemoglobin ($p<0.001$), RBC and WBC counts ($p<0.001$), N/L ratio ($p<0.01$), DNA damage ($p<0.001$) in brain cells, and plasma estradiol concentration ($p<0.05$), a significant decrease was observed in NO level ($p<0.05$) and antioxidant enzyme activities of MW-exposed mice. Our findings led us to conclude that a low level of MW irradiation-induced oxidative stress not only suppresses implantation, but it may also lead to deformity of the embryo in case pregnancy continues. We also suggest that MW radiation-induced oxidative stress by increasing ROS production in the body may lead to DNA strand breakage in the brain cells and implantation failure/resorption or abnormal pregnancy in mice.

Shahin S, Mishra V, Singh SP, Chaturvedi CM. 2.45-GHz microwave irradiation adversely affects reproductive function in male mouse, Mus musculus by inducing oxidative and nitrosative stress. Free Radic Res. 48(5):511-525, 2014.

Electromagnetic radiations are reported to produce long-term and short-term biological effects, which are of great concern to human health due to increasing use of devices emitting EMR especially microwave (MW) radiation in our daily life. In view of the unavoidable use of MW emitting devices (microwaves oven, mobile phones, Wi-Fi, etc.) and their harmful effects on biological system, it was thought worthwhile to investigate the long-term effects of low-level MW irradiation on the reproductive function of male Swiss strain mice and its mechanism of action. Twelve-week-old mice were exposed to non-thermal low-level 2.45-GHz MW radiation (CW for 2 h/day for 30 days, power density = 0.029812 mW/cm(2) and SAR = 0.018 W/Kg). Sperm count and sperm viability test were done as well as vital organs were processed to study different stress parameters. Plasma was used for testosterone and testis for 3β HSD assay. Immunohistochemistry of 3β HSD and nitric oxide synthase (i-NOS) was also performed in testis. We observed that MW irradiation induced a significant decrease in sperm count and sperm viability along with the decrease in seminiferous tubule diameter and degeneration of

seminiferous tubules. Reduction in testicular 3β HSD activity and plasma testosterone levels was also noted in the exposed group of mice. Increased expression of testicular i-NOS was observed in the MW-irradiated group of mice. Further, these adverse reproductive effects suggest that chronic exposure to nonionizing MW radiation may lead to infertility via free radical species-mediated pathway.

Shahin S, Singh SP, Chaturvedi CM 2.45 GHz microwave radiation induced oxidative and nitrosative stress mediated testicular apoptosis: Involvement of a p53 dependent bax-caspase-3 mediated pathway. Environ Toxicol 33(9):931-945, 2018.

Deleterious effects of MW radiation on the male reproduction are well studied. Previous reports although suggest that 2.45 GHz MW irradiation induced oxidative and nitrosative stress adversely affects the male reproductive function but the detailed molecular mechanism occurring behind it has yet to be elucidated. The aim of present study was to investigate the underlying detailed pathway of the testicular apoptosis induced by free radical load and redox imbalance due to 2.45 GHz MW radiation exposure and the degree of severity along with the increased exposure duration. Twelve-week old male mice were exposed to 2.45 GHz MW radiation [continuous-wave (CW) with overall average Power density of 0.0248 mW/cm2 and overall average whole body SAR value of 0.0146 W/kg] for 2 hr/day over a period of 15, 30, and 60 days. Testicular histology, serum testosterone, ROS, NO, MDA level, activity of antioxidant enzymes, expression of pro-apoptotic proteins (p53 and Bax), anti-apoptotic proteins (Bcl-2 and Bcl-xL), cytochrome-c, inactive/active caspase-3, and uncleaved PARP-1 were evaluated. Findings suggest that 2.45 GHz MW radiation exposure induced testicular redox imbalance not only leads to enhanced testicular apoptosis via p53 dependent Bax-caspase-3 mediated pathway, but also increases the degree of apoptotic severity in a duration dependent manner.

Sharma A, Kesari KK, Saxena VK, Sisodia R. Ten gigahertz microwave radiation impairs spatial memory, enzymes activity, and histopathology of developing mice brain. Mol Cell Biochem. 435(1-2):1-13, 2017.

For decades, there has been an increasing concern about the potential hazards of non-ionizing electromagnetic fields that are present in the environment and alarming as a major pollutant or electro-pollutant for health risk and neuronal diseases. Therefore, the objective of the present study was to explore the effects of 10 GHz microwave radiation on developing mice brain. Two weeks old mice were selected and divided into two groups (i) sham-exposed and (ii) microwave-exposed groups. Animals were exposed for 2 h/day for 15 consecutive days. After the completion of exposure, within an hour, half of the animals were autopsied immediately and others were allowed to attain 6 weeks of age for the follow-up study. Thereafter results were recorded in terms of various biochemical, behavioral, and histopathological parameters. Body weight result showed significant changes immediately after treatment, whereas non-significant changes were observed in mice attaining 6 weeks of age. Several other endpoints like brain weight, lipid peroxidation, glutathione, protein, catalase, and superoxide dismutase were also found significantly ($p < 0.05$) altered in mice whole brain. These significant differences were found immediately after exposure and also in follow-up on attaining 6 weeks of age in microwave exposure group. Moreover, statistically significant ($p < 0.001$) effect was investigated

in spatial memory of the animals, in learning to locate the position of platform in Morris water maze test. Although in probe trial test, sham-exposed animals spent more time in searching for platform into the target quadrant than in opposite or other quadrants. Significant alteration in histopathological parameters (qualitative and quantitative) was also observed in CA1 region of the hippocampus, cerebral cortex, and ansiform lobule of cerebellum. Results from the present study concludes that the brain of 2 weeks aged mice was very sensitive to microwave exposure as observed immediately after exposure and during follow-up study at 6 weeks of age.

Sharma S, Shukla S. Effect of electromagnetic radiation on redox status, acetylcholine esterase activity and cellular damage contributing to the diminution of the brain working memory in rats. J Chem Neuroanat. 106:101784, 2020.

Behavioral impairments are the most pragmatic outcome of long-term mobile uses but the underlying causes are still poorly understood. Therefore, the Aim of the present study to determine the possible mechanism of mobile induced behavioral alterations by observing redox status, cholinesterase activity, cellular, genotoxic damage and cognitive alterations in rat hippocampus. This study was carried out on 24 male Wistar rats, randomly divided into four groups (n = 6 in each group): group I consisted of sham-exposed (control) rats, group II-IV consisted of rats exposed to microwave radiation (900 MHz) at different time duration 1 h, 2 h, and 4 h respectively for 90 days. After 90 days of exposure, rats were assessing learning ability by using T-Maze. A significantly increased level of malondialdehyde (MDA) with concomitantly depleted levels of superoxide dismutase (SOD), catalase (CAT) and redox enzymes (GSH, GPX, GR, GST, G-6PDH) indicated an exposure of mobile emitted EMR induced oxidative stress by the depleted redox status of brain cells. The depletion in the acetylcholinesterase (AChE) level reveals altered neurotransmission in brain cells. Resultant cellular degeneration was also observed in the radiation-exposed hippocampus. Conclusively, the present study revealed that microwave radiation induces oxidative stress, depleted redox status, and causes DNA damage with the subsequent reduction in working memory in a time-dependent manner. This study provides insight over the associative reciprocity between redox status, cellular degeneration and reduced cholinergic activity, which presumably leads to the behavioral alterations following mobile emitted electromagnetic radiation.

Sharma S, Sharma P, Singh J, Bahel S, Dutta R, Vig AP1, Katnoria JK. Assessing cell viability and genotoxicity in Trigonella foenum-graecum L. exposed to 2100 MHz and 2300 MHz electromagnetic field radiations. Plant Physiol Biochem 219:109311, 2024.

The escalating utilization of wireless electronic devices, notably cellular phones, has led to a substantial augmentation in the levels of electromagnetic field radiation (EMF-r) within the environment. Consequently, an imperative arises to investigate the impact of these radiations on biological systems, specifically on plants. In this study, we examined the genotoxic and cytotoxic effects of 2100 MHz and 2300 MHz EMF-r on the Trigonella foenum-graecum L. test system, evaluating parameters such as percentage germination, growth characteristics, biochemical activities, cell viability and chromosomal aberrations. The roots and shoots of T. foenum-graecum L. were exposed to 2100 MHz and 2300 MHz EMF-r for varied exposure durations (0.5 h, 1 h, 2 h, 4 h and 8 h/day) (at a power density of 10.0 dBm). Substantial reductions in root and shoot lengths were observed after a exposure period of 4 h and 8 h at a frequency of 2100 MHz and 2300 MHz. Genotoxic studies revealed both physiological and clastogenic effects of EMF-r,

as evidenced by an increase in chromosomal aberrations (CAs). Biochemical analyses demonstrated elevated malondialdehyde levels and activities of various antioxidative enzymes following 2 h and 4 h per day exposure to 2100 MHz and 2300 MHz EMF-r. Chromosomal aberrations increased by 2.88%-14.86% and 2.84%-18.49% (0.5 h-8 h per day) exposure to 2100 MHz and 2300 MHz, respectively when compared to that of the control group. Exposure to electromagnetic fields (EMF-r) at both 2100 MHz and 2300 MHz resulted in reduced cell viability. This study examines the impact of electromagnetic fields (EMF-r) at 2100 MHz and 2300 MHz on plant root meristems. The results reveal more pronounced genotoxic effects at 2100 MHz, highlighting the frequency-dependent nature of EMF-r impacts. By providing insights into these frequency-specific effects, this research addresses a critical gap in understanding how EMF-r influences plant cellular health and offers guidance for mitigating potential environmental risks from mobile communication technologie.

Singh, K.V., Arya, R., Nirala, J..P, Sahu, D., Nanda, R.K., Rajamani, P. Effects of mobile phone electromagnetic radiation on rat hippocampus proteome. Environ. Toxicol. 37(4):836-847, 2022.

Worldwide, the number of mobile phone users has increased from 5.57 billion in 2011 to 6.8 billion in 2019. However, short- and long-term impact of the electromagnetic radiation emitting from mobile phones on tissue homeostasis with particular to brain proteome composition needs further investigation. In this study, we attempted a global proteome profiling study of rat hippocampus exposed to mobile phone radiation for 20 weeks (for 3 h/day for 5 days/week) to identify deregulated proteins and western blot analysis for validation. As a result, we identified 358 hippocampus proteins, of which 16 showed deregulation (log_2 (exposed/sham) $\geq \pm 1.0$, p-value <.05). Majority of these deregulated proteins grouped into three clusters sharing similar molecular pathways. A set of four proteins (Succinate-semialdehyde dehydrogenase: Aldh5a1, Na^+ K^+ transporting ATPase: Atp1b2, plasma membrane calcium transporting ATPase: PMCA and protein S100B) presenting each functional pathway were selected for validation. Western blot analysis of these proteins, in an independent sample set, corroborated the mass spectrometry findings. Aldh5a1 involve in cellular energy metabolism, both Atp1b2 and PMCA responsible for membrane transport and protein S100B have a neuroprotective role. In conclusion, we present a deregulated hippocampus proteome upon mobile phone radiation exposure, which might influence the healthy functioning of the brain.

Sirav, B., Seyhan, N. Effects of radiofrequency radiation exposure on blood-brain barrier permeability in male and female rats. Electromagn Biol Med. 30:253-260, 2011.

During the last several decades, numerous studies have been performed aiming at the question of whether or not exposure to radiofrequency radiation (RFR) influences the permeability of the blood-brain barrier (BBB). The objective of this study was to investigate the effect of RFR on the permeability of BBB in male and female Wistar albino rats. Right brain, left brain, cerebellum, and total brain were analyzed separately in the study. Rats were exposed to 0.9 and 1.8 GHz continuous-wave (CW) RFR for 20 min (at SARs of 4.26 mW/kg and 1.46 mW/kg, respectively) while under anesthesia. Control rats were sham-exposed. Disruption of BBB integrity was detected spectrophotometrically using the Evans-blue dye, which has been used as a BBB tracer and is known to be bound to serum albumin. Right brain, left brain, cerebellum,

and total brain were evaluated for BBB permeability. In female rats, no albumin extravasation was found in in the brain after RFR exposure. A significant increase in albumin was found in the brains of the RF-exposed male rats when compared to sham-exposed male brains. These results suggest that exposure to 0.9 and 1.8 GHz CW RFR at levels below the international limits can affect the vascular permeability in the brain of male rats. The possible risk of RFR exposure in humans is a major concern for the society. Thus, this topic should be investigated more thoroughly in the future.

Sırav, B., Seyhan, N. Effects of GSM modulated radio-frequency electromagnetic radiation on permeability of blood-brain barrier in male & female rats. J Chem Neuroanat. 75(Pt B):123-127, 2016.

With the increased use of mobile phones, their biological and health effects have become more important. Usage of mobile phones near the head increases the possibility of effects on brain tissue. This study was designed to investigate the possible effects of pulse modulated 900MHz and 1800MHz radio-frequency radiation on the permeability of blood-brain barrier of rats. Study was performed with 6 groups of young adult male and female wistar albino rats. The permeability of blood-brain barrier to intravenously injected evans blue dye was quantitatively examined for both control and radio-frequency radiarion exposed groups. For male groups; Evans blue content in the whole brain was found to be 0.08±0.01mg% in the control, 0.13±0.03mg% in 900MHz exposed and 0.26±0.05mg% in 1800MHz exposed animals. In both male radio-frequency radiation exposed groups, the permeability of blood-brain barrier found to be increased with respect to the controls ($p<0.01$). 1800MHz pulse modulated radio-frequency radiation exposure was found more effective on the male animals ($p<0.01$). For female groups; dye contents in the whole brains were 0.14±0.01mg% in the control, 0.24±0.03mg% in 900MHz exposed and 0.14±0.02mg% in 1800MHz exposed animals. No statistical variance found between the control and 1800MHz exposed animals ($p>0.01$). However 900MHz pulse modulated radio-frequency exposure was found effective on the permeability of blood-brain barrier of female animals. Results have shown that 20min pulse modulated radio-frequency radiation exposure of 900MHz and 1800MHz induces an effect and increases the permeability of blood-brain barrier of male rats. For females, 900MHz was found effective and it could be concluded that this result may due to the physiological differences between female and male animals. The results of this study suggest that mobile phone radation could lead to increase the permeability of blood-brain barrier under non-thermal exposure levels. More studies are needed to demonstrate the mechanisms of that breakdown.

Sokolovic D, Djindjic B, Nikolic J, Bjelakovic G, Pavlovic D, Kocic G, Krstic D, Cvetkovic T, Pavlovic V. Melatonin reduces oxidative stress induced by chronic exposure of microwave radiation from mobile phones in rat brain. J Radiat Res (Tokyo). 49(6):579-586, 2008.

PURPOSE: The aim of the study was to evaluate the intensity of oxidative stress in the brain of animals chronically exposed to mobile phones and potential protective effects of melatonin in reducing oxidative stress and brain injury. MATERIALS AND METHODS: Experiments were performed on Wistar rats exposed to microwave radiation during 20, 40 and 60 days. Four groups were formed: I group (control)- animals treated by saline, intraperitoneally (i.p.) applied daily during follow up, II group (Mel)- rats treated daily with melatonin (2 mg kg(-1) body

weight i.p.), III group (MWs)- microwave exposed rats, IV group (MWs + Mel)- MWs exposed rats treated with melatonin (2 mg kg(-1) body weight i.p.). The microwave radiation was produced by a mobile test phone (SAR = 0.043-0.135 W/kg). RESULTS: A significant increase in the brain tissue malondialdehyde (MDA) and carbonyl group concentration was registered during exposure. Decreased activity of catalase (CAT) and increased activity of xanthine oxidase (XO) remained after 40 and 60 days of exposure to mobile phones. Melatonin treatment significantly prevented the increase in the MDA content and XO activity in the brain tissue after 40 days of exposure while it was unable to prevent the decrease of CAT activity and increase of carbonyl group contents. CONCLUSION: We demonstrated two important findings; that mobile phones caused oxidative damage biochemically by increasing the levels of MDA, carbonyl groups, XO activity and decreasing CAT activity; and that treatment with the melatonin significantly prevented oxidative damage in the brain.

Sokolovic D, Djordjevic B, Kocic G, Veljkovic A, Marinkovic M, Basic J, Jevtovic-Stoimenov T, Stanojkovic Z, Sokolovic DM, Pavlovic V, Djindjic B, Krstic D. Melatonin protects rat thymus against oxidative stress caused by exposure to microwaves and modulates proliferation/apoptosis of thymocytes. Gen Physiol Biophys 32(1):79-90, 2013.

The aim of the study was to evaluate the effect of melatonin on oxidative stress, DNA fragmentation, apoptosis and proliferation in thymus tissue of rats exposed to microwaves. Wistar rats were divided in four groups: I – treated with saline; II – treated with melatonin; III – microwaves exposed; IV – microwaves exposed and melatonin treated. Melatonin (2 mg/kg i.p.) was administered daily. Animals were sacrificed after 20, 40 and 60 days. A significant increase in malondialdehyde and carbonyl group content, as well as decrease in catalase and increase in xanthine oxidase activity were registered under microwave exposure. Melatonin prevented the increase in malondialdehyde and carbonyl group content, and reversed the effect on catalase and xanthine oxidase activity. Both, alkaline and acid DNase activity were increased due to microwave exposure. Furthermore, microwaves caused increase in apoptosis rate (detected using Annexin V-FITC/PI kit) and reduced proliferative capacity of thymocytes (induced by ConA). However, melatonin caused decrease in alkaline and acid DNase activity, decrease in apoptotic rate and increase in proliferation rate of thymocytes. Melatonin exerts protective effects on rat thymocytes by modulating processes of apoptosis and proliferation, and causes decrease in DNA fragmentation and oxidative stress intensity under exposure to microwaves.

Sokolovic D, Djordjevic B, Kocic G, Stoimenov TJ, Stanojkovic Z, Sokolovic DM, et al. The Effects of Melatonin on Oxidative Stress Parameters and DNA Fragmentation in Testicular Tissue of Rats Exposed to Microwave Radiation. Adv Clin Exp Med. 24(3):429-436, 2015.

BACKGROUND: Microwaves from mobile phones are one of the environmental toxicants that are capable of compromising male fertility by inducing oxidative stress and apoptosis in the testes. Melatonin is a lipophilic tryptophan indole amine and a potent antioxidant. OBJECTIVES: The aim of the study was to evaluate the effect of melatonin treatment on oxidative stress parameters and DNA fragmentation in the testicular tissue of rats exposed to microwave radiation (4 h/day). MATERIAL AND METHODS: Adult Wistar rats were divided in 4 groups: I - treated with saline; II - treated with melatonin; III - exposed to microwaves; IV - exposed to microwaves and treated with melatonin. The melatonin (2 mg/kg ip) was administered daily. The animals were sacrificed after 20, 40 and 60 days. RESULTS: Melatonin

treatment prevented previously registered increases in malondialdehyde after only 20 days. Furthermore, it reversed the effects of microwave exposure on xanthine oxidase (after 40 days) and acid-DNase activity (after 20 days). However, neither protein carbonyl content nor catalase and alkaline Dnase activity were changed due to melatonin treatment. CONCLUSIONS: Melatonin exerts potent antioxidant effects in the testes of rats exposed to microwaves by decreasing the intensity of oxidative stress; it also reduces DNA fragmentation.

Somosy, Z., Thuroczy, G., Kubasova, T., Kovacs, J., Szabo, L.D. Effects of modulated and continuous microwave irradiation on the morphology and cell surface negative charge of 3T3 fibroblasts. Scanning Microsc. 5:1145-1155, 1991.

Mouse embryo 3T3 cells were irradiated with 2450 MHz continuous and low frequency (16 Hz) square modulated waves of absorbed energy ranging from 0.0024 to 2.4 mW/g. The low frequency modulated microwave irradiation yielded more morphological cell changes than did the continuous microwave fields of the same intensity. The amount of free negative charges (cationized ferritin binding) on cell surfaces decreased following irradiation by modulated waves but remained unchanged under the effect of a continuous field of the same dose. Modulated waves of 0.024 mW/g dose increased the ruffling activity of the cells, and caused ultrastructural alteration in the cytoplasm. Similar effects were experienced by continuous waves at higher (0.24 and 2.4 mW/g) doses.

Spandole-Dinu S, Catrina A-M, Voinea OC, Andone A, Radu S , Haidoiu C, Călborean O , Popescu DM , Suhăianu V, Baltag O , Tută L, Rosu G. Pilot study of the long-term effects of radiofrequency electromagnetic radiation exposure on the mouse brain. Int. J. Environ. Res. Public Health 20(4):3025, 2023.

The increasing radiofrequency (RF) electromagnetic radiation pollution resulting from the development and use of technologies utilizing RF has sparked debate about the possible biological effects of said radiation. Of particular concern is the potential impact on the brain, due to the close proximity of communication devices to the head. The main aim of this study was to examine the effects of long-term exposure to RF on the brains of mice in a real-life scenario simulation compared to a laboratory setting. The animals were exposed continuously for 16 weeks to RF using a household Wi-Fi router and a laboratory device with a frequency of 2.45 GHz, and were compared to a sham exposed group. Before and after exposure, the mice underwent behavioral tests (open-field test and Y-maze); at the end of the exposure period, the brain was harvested for histopathological analysis and assessment of DNA methylation levels. Long-term exposure of mice to 2.45 GHz RF radiation increased their locomotor activity, yet did not cause significant structural or morphological changes in their brains. Global DNA methylation was lower in exposed mice compared to sham mice. Further research is needed to understand the mechanisms behind these effects and to understand the potential effects of RF radiation on brain function.

Stagg, R.B., Thomas, W.J., Jones, R.A., Adey, W.R. DNA synthesis and cell proliferation in C6 glioma and primary glial cells exposed to a 836.55 MHz modulated radiofrequency field. Bioelectromagnetics. 18:230-236, 1997.

We have tested the hypothesis that modulated radiofrequency (RF) fields may act as a tumor-promoting agent by altering DNA synthesis, leading to increased cell proliferation. In vitro tissue cultures of transformed and normal rat glial cells were exposed to an 836.55 MHz, packet-modulated RF field at three power densities: 0.09, 0.9, and 9 mW/cm2, resulting in specific absorption rates (SARs) ranging from 0.15 to 59 muW/g. TEM-mode transmission-line cells were powered by a prototype time-domain multiple-access (TDMA) transmitter that conforms to the North American digital cellular telephone standard. One sham and one energized TEM cell were placed in standard incubators maintained at 37 degrees C and 5% CO2. DNA synthesis experiments at 0.59-59 muW/g SAR were performed on log-phase and serum-starved semiquiescent cultures after 24 h exposure. Cell growth at 0.15-15 muW/g SAR was determined by cell counts of log-phase cultures on days 0, 1, 5, 7, 9, 12, and 14 of a 2 week protocol. Results from the DNA synthesis assays differed for the two cell types. Sham-exposed and RF-exposed cultures of primary rat glial cells showed no significant differences for either log-phase or serum-starved condition. C6 glioma cells exposed to RF at 5.9 muW/g SAR (0.9 mW/cm2) exhibited small (20-40%) significant increases in 38% of [3H]thymidine incorporation experiments. Growth curves of sham and RF-exposed cultures showed no differences in either normal or transformed glial cells at any of the power densities tested. Cell doubling times of C6 glioma cells [sham (21.9 +/- 1.4 h) vs. field (22.7 +/- 3.2 h)] also demonstrated no significant differences that could be attributed to altered DNA synthesis rates. Under these conditions, this modulated RF field did not increase cell proliferation of normal or transformed cultures of glial origin.

Stankiewicz, W., Dąbrowski, M.P., Kubacki, R., Sobiczewska, E., Szmigielski, S. Immunotropic lnfluence of 900 MHz microwave GSM signal on human blood immune cells activated in vitro. Electromagn Biol Med. 25: 45-51, 2006.

In an earlier study we reported that G(o) phase peripheral blood mononulclear cells (PBMC) exposed to low-level (SAR = 0.18 W/kg) pulse-modulated 1300 MHz microwaves and subsequently cultured, demonstrate changed immune activity (Dabrowski et al., 2003). We investigated whether cultured immune cells induced into the active phases of cell cycle (G(1), S) and then exposed to microwaves will also be sensitive to electromagnetic field. An anechoic chamber of our design containing a microplate with cultured cells and an antenna emitting microwaves (900 MHz simulated GSM signal, 27 V/m, SAR 0.024 W/kg) was placed inside the ASSAB incubator. The microcultures of PBMC exposed to microwaves demonstrated significantly higher response to mitogens and higher immunogenic activity of monocytes (LM index) than control cultures. LM index, described in detail elsewhere (Dabrowski et al., 2001), represents the monokine influence on lymphocyte mitogenic response. The results suggest that immune activity of responding lymphocytes and monocytes can be additionally intensified by 900 MHz microwaves.

Stasinopoulou M, Fragopoulou AF, Stamatakis A, Mantziaras G, Skouroliakou K, Papassideri IS, Stylianopoulou F, Lai H, Kostomitsopoulos N, Margaritis LH. Effects of pre- and postnatal exposure to 1880-1900MHz DECT base radiation on development in the rat. Reprod Toxicol. 65:248-262, 2016.

In the present study, to evaluate the effects of wireless 1880-1900MHz Digital Enhanced Communication Telephony (DECT) base radiation on fetal and postnatal development, Wistar rats were exposed at an average electric field intensity of 3.7V/m, 12h/day, during pregnancy. After parturition, a group of dams and offspring were similarly exposed for another 22days. Controls were sham-exposed. The data showed that DECT base radiation exposure caused heart rate increase in the embryos on the 17th day of pregnancy. Moreover, significant changes on the newborns' somatometric characteristics were noticed. Pyramidal cell loss and glia fibrilliary acidic protein (GFAP) over-expression were detected in the CA4 region of the hippocampus of the 22-day old pups that were irradiated either during prenatal life or both pre- and postnatally. Changes in the integrity of the brain in the 22-day old pups could potentially be related to developmental behavioral changes during the fetal period.

Sueiro-Benavides RA, Leiro-Vidal JM, Rodríguez-González JA, Ares-Pena FJ, López-Martín E. Radiofrequency Fields at 2.45 GHz Reprogram Mitochondria-Lysosome Crosstalk and Modulate the Survival/Death of Macrophages Exposed to LPS and/or the SARS-CoV-2 Spike Protein. Int J Mol Sci. 27(9):3813, 2026.

The redox mechanisms of RAW 264.7 macrophages exposed to 2.45 GHz RF-EMF at subthermal specific absorption rates and to lipopolysaccharide (LPS) and/or the SARS-CoV-2 spike protein (CSP) were investigated. To this end, cellular responses (lysosomal and mitochondrial activity, nitric oxide (NO) production, and cell survival/death) were measured after 6, 24, and 48 h. Selective loss of viability in cells exposed to RF and LPS was observed at 6 h, consistent with early defects in membrane permeability. Lysosomal activity was significantly enhanced in cells treated with RF + LPS. Mitochondrial activity decreased in cells exposed to RF + LPS at 6 h and increased in cells treated with RF + CPS/LPS. Cell viability decreased greatly in cells treated with LPS and CSP + LPS after 24, particularly after 48 h. Nitrite levels peaked in non-irradiated cells treated with RF + LPS and in CSP + LPS at 24 h and decreased in irradiated cells after 48 h. Irradiation affected selection of the death mode: apoptosis decreased or remained unchanged in cells subjected to any of the treatments, while necrosis increased in cells treated with CPS, LPS, or both for 48 h. The combination of RF-EMF and infectious agents reprogrammed the interaction between mitochondria/lysosomes/nitric oxide (NO)/cell death in macrophages in a time- and stimulus-dependent manner.

Suhhova, A., Bachmann, M., Karai, D., Lass, J., Hinrikus, H. Effect of microwave radiation on human EEG at two different levels of exposure. Bioelectromagnetics. 34:264-74, 2013.

This study is aimed at evaluating the effect of microwave radiation on human brain bioelectric activity at different levels of exposure. For this purpose, 450 MHz microwave exposure modulated at 40 Hz frequency was applied to a group of 15 healthy volunteers at two different specific absorption rate (SAR) levels: a higher level of 0.303 W/kg (field strength 24.5 V/m) and a lower level of 0.003 W/kg (field strength 2.45 V/m). Ten exposure cycles (1 min off and 1 min on) at fixed SAR values were applied. A resting eyes-closed electroencephalogram (EEG) was continuously recorded. Results showed a statistically significant increase in the EEG power in the EEG beta2 (157%), beta1 (61%) and alpha (68%) frequency bands at the higher SAR level, and in the beta2 (39%) frequency band at the lower SAR level. Statistically significant changes were detected for six individual subjects in the EEG alpha band and four subjects in the beta1

and beta2 bands at the higher SAR level; three subjects were affected in the alpha, beta1 and beta2 bands at the lower SAR level. The study showed that decreasing the SAR 100 times reduced the related changes in the EEG three to six times and the number of affected subjects, but did not exclude the effect.

Sun, Y., Zong, L., Gao, Z., Zhu, S., Tong, J., Cao, Y. Mitochondrial DNA damage and oxidative damage in HL-60 cells exposed to 900 MHz radiofrequency fields. Mutat Res. 797-799:7-14, 2017.

HL-60 cells, derived from human promyelocytic leukemia, were exposed to continuous wave 900 MHz radiofrequency fields (RF) at 120 $\mu W/cm^2$ power intensity for 4 h/day for 5 consecutive days to examine whether such exposure is capable damaging the mitochondrial DNA (mtDNA) mediated through the production of reactive oxygen species (ROS). In addition, the effect of RF exposure was examined on 8-hydroxy-2′-dexoyguanosine (8-OHdG) which is a biomarker for oxidative damage and on the mitochondrial synthesis of adenosine triphosphate (ATP) which is the energy required for cellular functions. The results indicated a significant increase in ROS and significant decreases in mitochondrial transcription factor A, mtDNA polymerase gamma, mtDNA transcripts and mtDNA copy number in RF-exposed cells compared with those in sham-exposed control cells. In addition, there was a significant increase in 8-OHdG and a significant decrease in ATP in RF-exposed cells. The response in positive control cells exposed to gamma radiation (GR, which is also known to induce ROS) was similar to those in RF-exposed cells. Thus, the overall data indicated that RF exposure was capable of inducing mtDNA damage mediated through ROS pathway which also induced oxidative damage. Prior-treatment of RF- and GR-exposed the cells with melatonin, a well-known free radical scavenger, reversed the effects observed in RF-exposed cells.

Syed Taha SMA, Jaffar FHF, Hairulazam A, Vijay S, Jamaludin N, Zulkefli AF, Mat Ros MF, Osman K, Zakaria Z, Mohd Bahar MAA, Ibrahim SF. Testicular Heat-Shock Protein Expression in Rats Following 3.5 GHz and 24 GHz RF-EMF Exposure. Int J Mol Sci. 27(8):3452, 2026.

The expansion of fifth-generation (5G) wireless networks has increased environmental exposure to mid-band and millimeter-wave radiofrequency electromagnetic fields (RF-EMF), but their molecular effects on male reproductive tissues remain insufficiently understood. This study evaluated whether repeated exposure to 3.5 GHz and 24 GHz RF-EMF alters testicular stress-associated molecular responses by integrating electromagnetic dosimetry with an in vivo rat model. Whole-body specific absorption rate (SAR) and 10 g peak SAR were estimated using a rat voxel model and scaled to the 20 cm antenna-to-cage geometry used during exposure. Thirty-six adult male Sprague Dawley rats were allocated to sham, 3.5 GHz, or 24 GHz groups and exposed for 1 h/day or 7 h/day over 60 days. Testes were examined histologically and assessed for HSP27, HSP70, and HSP90 protein expression. SAR values were low overall, although absorption was higher at 3.5 GHz than at 24 GHz. Histological evaluation showed preserved seminiferous tubule architecture without consistent structural injury. In contrast, molecular analysis demonstrated frequency- and duration-dependent modulation of heat shock proteins, including early HSP70 downregulation at both frequencies, followed by HSP90 upregulation at 3.5 GHz and HSP27 upregulation at 24 GHz. These findings indicate that low-level 5G-relevant

RF-EMF exposure can modify molecular stress responses in testicular tissue even in the absence of overt histological damage.

Szymański, Ł., Sobiczewska, E., Cios, A., Szymanski, P., Ciepielak, M., Stankiewicz, W. Immunotropic effects in cultured human blood mononuclear cells exposed to a 900 MHz pulse-modulated microwave field. J Radiat Res. 61:27-33, 2020.

The specific biological effect of electromagnetic field (EMF) remains unknown even though devices present in our daily lives, such as smartphones and Wi-Fi antennae increase the environmental level of electromagnetic radiation. It is said that the human immune system is able to react to discrete environmental stimuli like EMF. To investigate the effect of 900 MHz microwave stimulation on the immune system our research aimed to analyze lymphocyte proliferation and observe and assess the basic immunoregulatory activities using a newly developed and improved anechoic chamber. Samples of mononuclear cells (PBMC) isolated from the blood of healthy donors were exposed to 900 MHz pulse-modulated radiofrequency radiation (20 V/m, SAR 0.024 W/kg) twice (15 min each) or left without irradiation (control group). Subsequently, the control and exposed cells were set up to determine several parameters characterizing T cell immunocompetence and monocyte immunogenic activity. Although the microcultures of PBMC exposed to radiofrequency radiation demonstrated higher immunogenic activity of monocytes (LM index) and T-cell response to concanavalin A than control cultures after first exposure, this parameter decreased after a second stimulation. Saturation of the interleukin-2 (IL-2) receptor rose significantly after the second day of exposure. On the other hand, response to mitogen dropped after EMF stimulation. The results suggest that PBMC are able to overcome stress caused by mitogens after stimulation with 900 MHz radiation

Tahir E, Karadayı AA, Gürgen SG, Engiz BK, Turgut A. Effect of 2.45 GHz microwave radiation on the inner ear: A histopathological study on 2.45 GHz microwave radiation and cochlea. J Int Adv Otol 20(1):35-43, 2024.

Background: The present study aims to determine the possible low dose-dependent adverse effects of 2.45 GHz microwave exposure and Wi-Fi frequency on the cochlea. **Methods:** Twelve pregnant female rats (n=12) and their male newborns were exposed to Wi-Fi frequencies with varying electric field values of 0.6, 1.9, 5, 10 V/m, and 15 V/m during the 21-day gestation period and 45 days after birth, except for the control group. Auditory brainstem response testing was performed before exposure and sacrification. After removal of the cochlea, histopathological examination was conducted by immunohistochemistry methods using caspase (cysteine-aspartic proteases, cysteine aspartates, or cysteine-dependent aspartate-directed proteases)-3, -9, and terminal deoxynucleotidyl transferase dUTP nick end labeling (TUNEL). Kruskal-Wallis and Wilcoxon tests and multivariate analysis of variance were used. **Results:** Auditory brainstem response thresholds in postexposure tests increased statistically significantly at 5 V/m and above doses. When the number of apoptotic cells was compared in immunohistochemistry examination, significant differences were found at 10 V/m and 15 V/m doses ($F(5,15)=23.203$, $P=.001$; Pillai's trace=1.912, $\eta 2=0.637$). As the magnitude of the electric field increased, all histopathological indicators of apoptosis increased. The most significant effect was noted on caspase-9 staining ($\eta 2$ c9=0.996), followed by caspase-3 ($\eta 2$ c3=0.991), and TUNEL staining ($\eta 2$ t=0.801).

Caspase-3, caspase-9, and TUNEL-stained cell densities increased directly by increasing the electric field and power values. **Conclusion:** Apoptosis and immune activity in the cochlea depend on the electric field and power value. Even at low doses, the electromagnetic field in Wi-Fi frequency damages the inner ear and causes apoptosis.

Tan FC, Yalçin B, Yay AH, Tan B, Yeğin K, Daşdağ S. Effects of pre and postnatal 2450 MHz continuous wave (CW) radiofrequency radiation on thymus: Four generation exposure. Electromagn Biol Med 41(3):315-324, 2022.

This study aims to investigate the effects of pre- and postnatal 2450 MHz continuous wave (CW) radiofrequency radiation (RFR) on the thymus of rats spanning four generations. Four groups; sham, irradiated female, irradiated male, irradiated male and female, each consisting of four rats (one male and three females), were created. During the experiment, rats in the exposure groups were whole-body exposed to 2450 MHz CW-RFR for 12 h/day. Irradiation started one month before the fertilization in the experimental group. When the offspring were two months old, four rats, one male and three female, were allocated for the second-generation study. The remaining offspring were sacrificed under general anesthesia, and their thymuses were removed. The same procedure was applied to the next generation. Two months after the second generation gave birth, third-generation rats were decapitated, and their thymuses were removed. In all groups, cortex, medulla and resident cells could be clearly distinguished in the second and third generations. No differences were observed between the control and two experimental groups, defined as irradiated female and irradiated male. In contrast, vascularization was observed in the thymus of the fourth-generation offspring of the group where both males and females were irradiated. The number of offspring and mass of all rats decreased in the third-generation group. Pre-and postnatal 2450 MHz continuous wave radiofrequency radiation exposure may potentially affect the thymus of future generations.

Tang, J., Zhang, Y., Yang, L., Chen, Q., Tan, L., Zuo, S., Feng, H., Chen, Z., Zhu, G. Exposure to 900 MHz electromagnetic fields activates the mkp-1/ERK pathway and causes blood-brain barrier damage and cognitive impairment in rats. Brain Res. 1601:92-101, 2015.

With the rapid increase in the number of mobile phone users, the potential adverse effects of the electromagnetic field radiation emitted by a mobile phone has become a serious concern. This study demonstrated, for the first time, the blood-brain barrier and cognitive changes in rats exposed to 900 MHz electromagnetic field (EMF) and aims to elucidate the potential molecular pathway underlying these changes. A total of 108 male Sprague-Dawley rats were exposed to a 900 MHz, 1 mW/cm(2) EMF or sham (unexposed) for 14 or 28 days (3h per day). The specific energy absorption rate (SAR) varied between 0.016 (whole body) and 2 W/kg (locally in the head). In addition, the Morris water maze test was used to examine spatial memory performance determination. Morphological changes were investigated by examining ultrastructural changes in the hippocampus and cortex, and the Evans Blue assay was used to assess blood brain barrier (BBB) damage. Immunostaining was performed to identify heme oxygenase-1 (HO-1)-positive neurons and albumin extravasation detection. Western blot was used to determine HO-1 expression, phosphorylated ERK expression and the upstream mediator, mkp-1 expression. We found that the frequency of crossing platforms and the percentage of time spent in the target quadrant were lower in rats exposed to EMF for 28 days than in rats exposed to EMF for 14 days

and unexposed rats. Moreover, 28 days of EMF exposure induced cellular edema and neuronal cell organelle degeneration in the rat. In addition, damaged BBB permeability, which resulted in albumin and HO-1 extravasation were observed in the hippocampus and cortex. Thus, for the first time, we found that EMF exposure for 28 days induced the expression of mkp-1, resulting in ERK dephosphorylation. Taken together, these results demonstrated that exposure to 900 MHz EMF radiation for 28 days can significantly impair spatial memory and damage BBB permeability in rat by activating the mkp-1/ERK pathway.

Tas M, Dasdag S, Akdag MZ, Cirit U, Yegin K, Seker U, Ozmen MF, Eren LB. Long-term effects of 900 MHz radiofrequency radiation emitted from mobile phone on testicular tissue and epididymal semen quality. Electromagn Biol Med. 33(3):216-222, 2014.

The purpose of this study is to bridge this gap by investigating effects of long term 900 MHz mobile phone exposure on reproductive organs of male rats. The study was carried out on 14 adult Wistar Albino rats by dividing them randomly into two groups (n: 7) as sham group and exposure group. Rats were exposed to 900 MHz radiofrequency (RF) radiation emitted from a GSM signal generator. Point, 1 g and 10 g specific absorption rate (SAR) levels of testis and prostate were found as 0.0623 W/kg, 0.0445 W/kg and 0.0373 W/kg, respectively. The rats in the exposure group were subject to RF radiation 3 h per day (7 d a week) for one year. For the sham group, the same procedure was applied, except the generator was turned off. At the end of the study, epididymal sperm concentration, progressive sperm motility, abnormal sperm rate, all-genital organs weights and testis histopathology were evaluated. Any differences were not observed in sperm motility and concentration ($p > 0.05$). However, the morphologically normal spermatozoa rates were found higher in the exposure group ($p < 0.05$). Although histological examination showed similarity in the seminiferous tubules diameters in both groups, tunica albuginea thickness and the Johnsen testicular biopsy score were found lower in the exposure group ($p < 0.05$, $p < 0.0001$). In conclusion, we claim that long-term exposure of 900 MHz RF radiation alter some reproductive parameters. However, more supporting evidence and research is definitely needed on this topic.

Tattersall, J.E., Scott, I.R., Wood, S.J., Nettell. J.J., Bevir, M.K., Wang,. Z, Somasiri, N.P., Chen, X. Effects of low intensity radiofrequency electromagnetic fields on electrical activity in rat hippocampal slices. Brain Res. 904: 43-53, 2001.

Slices of rat hippocampus were exposed to 700 MHz continuous wave radiofrequency (RF) fields (25.2-71.0 V m(-1), 5-15 min exposure) in a stripline waveguide. At low field intensities, the predominant effect on the electrically evoked field potential in CA1 was a potentiation of the amplitude of the population spike by up to 20%, but higher intensity fields could produce either increases or decreases of up to 120 and 80%, respectively, in the amplitude of the population spike. To eliminate the possibility of RF-induced artefacts due to the metal stimulating electrode, the effect of RF exposure on spontaneous epileptiform activity induced in CA3 by 4-aminopyridine (50-100 microM) was investigated. Exposure to RF fields (50.0 V m(-1)) reduced or abolished epileptiform bursting in 36% of slices tested. The maximum field intensity used in these experiments, 71.0 V m(-1), was calculated to produce a specific absorption rate (SAR) of between 0.0016 and 0.0044 W kg(-1) in the slices. Measurements with a Luxtron fibreoptic probe confirmed that there was no detectable temperature change (+/- 0.1 degrees C) during a 15

min exposure to this field intensity. Furthermore, imposed temperature changes of up to 1 degrees C failed to mimic the effects of RF exposure. These results suggest that low-intensity RF fields can modulate the excitability of hippocampal tissue in vitro in the absence of gross thermal effects. The changes in excitability may be consistent with reported behavioural effects of RF fields.

Tkalec, M., Stambuk, A., Srut, M., Malarić, K., Klobučar, G.I. Oxidative and genotoxic effects of 900 MHz electromagnetic fields in the earthworm Eisenia fetida. Ecotoxicol Environ Saf. 90:7-12, 2013.

Accumulating evidence suggests that exposure to radiofrequency electromagnetic field (RF-EMF) can have various biological effects. In this study the oxidative and genotoxic effects were investigated in earthworms Eisenia fetida exposed in vivo to RF-EMF at the mobile phone frequency (900 MHz). Earthworms were exposed to the homogeneous RF-EMF at field levels of 10, 23, 41 and 120 V m(-1) for a period of 2h using a Gigahertz Transversal Electromagnetic (GTEM) cell. At the field level of 23 V m(-1) the effect of longer exposure (4h) and field modulation (80% AM 1 kHz sinusoidal) was investigated as well. All exposure treatments induced significant genotoxic effect in earthworms coelomocytes detected by the Comet assay, demonstrating DNA damaging capacity of 900 MHz electromagnetic radiation. Field modulation additionally increased the genotoxic effect. Moreover, our results indicated the induction of antioxidant stress response in terms of enhanced catalase and glutathione reductase activity as a result of the RF-EMF exposure, and demonstrated the generation of lipid and protein oxidative damage. Antioxidant responses and the potential of RF-EMF to induce damage to lipids, proteins and DNA differed depending on the field level applied, modulation of the field and duration of E. fetida exposure to 900 MHz electromagnetic radiation. Nature of detected DNA lesions and oxidative stress as the mechanism of action for the induction of DNA damage are discussed

Tomruk A, Ozgur-Buyukatalay E, Ozturk GG, Ulusu NN. Short-term exposure to radiofrequency radiation and metabolic enzymes' activities during pregnancy and prenatal development. Electromagn Biol Med 41(4):370-378, 2022.

Radiofrequency radiation (RFR) as an environmental and physical pollutant may induce vulnerability to toxicity and disturb fetal development. Therefore, the potential health effects of short-term mobile phone like RFR exposure (GSM 1800 MHz; 14 V/m, 2 mW/kg specific absorption rate (SAR) during 15 min/day for a week) during pregnancy and also the development of fetuses were investigated. Hepatic glucose regulation and glutathione-dependent enzymes' capacities were biochemically analyzed in adult (female) and pregnant New Zealand White rabbits. Pregnant rabbits' two-day-old offspring were included to understand their developmental stages under short-term maternal RFR exposure. We analyzed two regulatory enzymes in the oxidative phase of phosphogluconate pathways to interpret the cytosolic NADPH's biosynthesis for maintaining mitochondrial energy metabolism. Moreover, the efficiencies of maternal glutathione-dependent enzymes on both the removal of metabolic disturbances during pregnancy and fetus development were examined. Whole-body RFR exposures were applied to pregnant animals from the 15th to the 22nd day of their gestations, i.e., the maturation periods of tissues and organs for rabbit fetuses. There were significant differences in hepatic glucose regulation

and GSH-dependent enzymes' capacities with pregnancy and short-term RFR exposure. Consequently, we observed that intrauterine exposure to RFR might lead to cellular ROS-dependent disturbances in metabolic activity and any deficiency in the intracellular antioxidant (ROS-scavenging) system. This study might be a novel insight into further studies on the possible effects of short-term RF exposure and prenatal development.

Topal Z, Hanci H, Mercantepe T, Erol HS, Keleş ON, Kaya H, Mungan S, Odaci E. The effects of prenatal long-duration exposure to 900-MHz **electromagnetic field on the 21-day-old newborn male rat liver. Turk J Med Sci. 45(2):291-297, 2015.**

BACKGROUND/AIM: To determine what effect a 900-MHz electromagnetic field (EMF) applied in the prenatal period would have on the liver in the postnatal period. MATERIALS AND METHODS: At the start of the study, adult pregnant rats were divided into two groups, control and experimental. The experimental group was exposed to a 900-MHz EMF for 1 h daily during days 13-21 of pregnancy. After birth, no procedure was performed on either mothers or pups. Male rat pups (n = 6) from the control group mothers (CGMR) and male rat pups (n = 6) from the experimental group mothers (EGMR) were sacrificed on postnatal day 21. RESULTS: Biochemical analyses showed that malondialdehyde and superoxide dismutase values increased and glutathione levels decreased in the EGMR pups. Marked hydropic degeneration in the parenchyma, particularly in pericentral regions, was observed in light microscopic examination of EGMR sections stained with hematoxylin and eosin. Examinations under transmission electron microscope revealed vacuolization in the mitochondria, expansion in the endoplasmic reticulum, and necrotic hepatocytes. CONCLUSION: The study results show that a 900-MHz EMF applied in the prenatal period caused oxidative stress and pathological alterations in the liver in the postnatal period.

Tripathi R, Banerjee SK, Nirala JP, Mathur R. Exposure to electromagnetic fields from mobile phones and fructose consumption coalesce to perturb metabolic regulators AMPK/SIRT1-UCP2/FOXO1 in growing rats. Biomed Environ Sci 36(11):1045-1058, 2023.

Objective: In this study, the combined effect of two stressors, namely, electromagnetic fields (EMFs) from mobile phones and fructose consumption, on hypothalamic and hepatic master metabolic regulators of the AMPK/SIRT1-UCP2/FOXO1 pathway were elucidated to delineate the underlying molecular mechanisms of insulin resistance. **Methods:** Weaned Wistar rats (28 days old) were divided into 4 groups: Normal, Exposure Only (ExpO), Fructose Only (FruO), and Exposure and Fructose (EF). Each group was provided standard laboratory chow *ad libitum* for 8 weeks . Additionally, the control groups, namely, the Normal and FruO groups, had unrestricted access to drinking water and fructose solution (15%), respectively. Furthermore, the respective treatment groups, namely, the ExpO and EF groups, received EMF exposure (1,760 MHz, 2 h/day x 8 weeks). In early adulthood, mitochondrial function, insulin receptor signaling, and oxidative stress signals in hypothalamic and hepatic tissues were assessed using western blotting and biochemical analysis. **Result:** In the hypothalamic tissue of EF, SIRT1, FOXO 1, p-PI3K, p-AKT, Complex III, UCP2, MnSOD, and catalase expressions and OXPHOS and GSH activities were significantly decreased ($P < 0.05$) compared to the Normal, ExpO, and FruO groups. In hepatic tissue of EF, the p-AMPKα, SIRT1, FOXO1, IRS1, p-PI3K, Complex I, II, III, IV, V, UCP2, and MnSOD expressions and the activity of OXPHOS, SOD, catalase, and GSH

were significantly reduced compared to the Normal group ($P < 0.05$). **Conclusion:** The findings suggest that the combination of EMF exposure and fructose consumption during childhood and adolescence in Wistar rats disrupts the closely interlinked and multi-regulated crosstalk of insulin receptor signals, mitochondrial OXPHOS, and the antioxidant defense system in the hypothalamus and liver.

Trosić, I. , Pavicić, I. Disturbance of cell proliferation in response to mobile phone frequency radiation. Arh Hig Rada Toksikol. 60:109-115, 2009.

The aim of study was to determine the influence of mobile phone frequency radiation on the proliferation, cytoskeleton structure, and mitotic index of V79 cells after 1 h, 2 h, and 3 h of exposure. V79 cells were cultured in standard laboratory conditions and exposed to continuous-wave (CW) RF/MW radiation of 935 MHz, electric field strength of (8.2+/-0.3) V m(-1), and specific absorption rate (SAR) of 0.12 W kg(-1). To identify proliferation kinetics, the cells were counted for each hour of exposure 24 h, 48 h, 72 h, and 96 h after respective exposures. Microtubule proteins were determined using specific immunocytochemical methods. Cell smears were analysed under a fluorescent microscope. The study included negative and positive controls. Mitotic index was determined by estimating the number of dividing cells 24 h after exposure and dividing it with the total number of cells. In comparison to the controls, cell proliferation declined in cells exposed for three hours 72 h after irradiation ($p < 0.05$). Microtubule structure was clearly altered immediately after three hours of irradiation ($p < 0.05$). The mitotic index in RF/MW-exposed cells did not differ from negative controls. However, even if exposure did not affect the number of dividing cells, it may have slowed down cell division kinetics as a consequence of microtubule impairment immediately after exposure.

Tsoy, A., Saliev, T., Abzhanova, E., Turgambayeva, A., Kaiyrlykyzy, A., Akishev, M., Saparbayev, S., Umbayev, B., Askarova, S. The effects of mobile phone radiofrequency electromagnetic fields on β-amyloid-Induced oxidative stress in human and rat primary astrocytes. Neurosci.408:46-57, 2019.

Amyloid beta peptide (Aβ) is implicated in the development of pathological reactions associated with Alzheimer's disease (AD), such as oxidative stress, neuro-inflammation and death of brain cells. Current pharmacological approaches to treat AD are not able to control the deposition of Aβ and suppression of Aβ-induced cellular response. There is a growing body of evidence that exposure to radiofrequency electromagnetic field (RF-EMF) causes a decrease of beta-amyloid deposition in the brains and provides cognitive benefits to Alzheimer's Tg mice. Herein, we investigated the effects of mobile phone radiofrequency EMF of 918 MHz on reactive oxygen species (ROS) formation, mitochondrial membrane potential (MMP), activity of NADPH-oxidase, and phosphorylation of p38MAPK and ERK1/2 kinases in human and rat primary astrocytes in the presence of $A\beta_{42}$ and H_2O_2. Our data demonstrate that EMF is able to reduce $A\beta_{42}$- and H_2O_2-induced cellular ROS, abrogate $A\beta_{42}$-induced production of mitochondrial ROS and the co-localization between the cytosolic (p47-phox) and membrane (gp91-phox) subunits of NADPH oxidase, while increasing MMP, and inhibiting H_2O_2-induced phosphorylation of p38MAPK and ERK1/2 in primary astrocytes. Yet, EMF was not able to modulate alterations in the phosphorylation state of the MAPKs triggered by $A\beta_{42}$. Our findings provide an insight into

the mechanisms of cellular and molecular responses of astrocytes on RF-EMF exposure and indicate the therapeutic potential of RF-EMF for the treatment of Alzheimer's disease.

Tsybulin, O., Sidorik, E., Brieieva, O., Buchynska, L., Kyrylenko, S., Henshel, D., Yakymenko, I. GSM 900 MHz cellular phone radiation can either stimulate or depress early embryogenesis in Japanese quails depending on the duration of exposure. Int J Radiat Biol. 89:756-763, 2013.

Purpose: Our study was designed to assess the effects of low intensity radiation of a GSM (Global System for Mobile communication) 900 MHz cellular phone on early embryogenesis in dependence on the duration of exposure.**Materials and methods:** Embryos of Japanese Quails were exposed in ovo to GSM 900 MHz cellular phone radiation during initial 38 h of brooding or alternatively during 158 h (120 h before brooding plus initial 38 h of brooding) discontinuously with 48 sec ON (average power density 0.25 μW/cm(2), specific absorption rate 3 μW/kg) followed by 12 sec OFF intervals. A number of differentiated somites were assessed microscopically. Possible DNA damage evoked by irradiation was assessed by an alkaline comet assay. **Results:** Exposure to radiation from a GSM 900 MHz cellular phone led to a significantly altered number of differentiated somites. In embryos irradiated during 38 h the number of differentiated somites increased ($p < 0.001$), while in embryos irradiated during 158 h this number decreased ($p < 0.05$). The lower duration of exposure led to a significant ($p < 0.001$) decrease in a level of DNA strand breaks in cells of 38-h embryos, while the higher duration of exposure resulted in a significant ($p < 0.001$) increase in DNA damage as compared to the control. **Conclusion:** Effects of GSM 900 MHz cellular phone radiation on early embryogenesis can be either stimulating or deleterious depending on the duration of exposure.

Türedi S, Hancı H, Topal Z, Ünal D, Mercantepe T, Bozkurt I, Kaya H, Odacı E. The effects of prenatal exposure to a 900-MHz electromagnetic field on the 21-day-old male rat heart. Electromagn Biol Med 34(4):390-397, 2015.

The growing spread of mobile phone use is raising concerns about the effect on human health of the electromagnetic field (EMF) these devices emit. The purpose of this study was to investigate the effects on rat pup heart tissue of prenatal exposure to a 900 megahertz (MHz) EMF. For this purpose, pregnant rats were divided into experimental and control groups. Experimental group rats were exposed to a 900 MHz EMF (1 h/d) on days 13-21 of pregnancy. Measurements were performed with rats inside the exposure box in order to determine the distribution of EMF intensity. Our measurements showed that pregnant experimental group rats were exposed to a mean electrical field intensity of 13.77 V/m inside the box (0.50 W/m(2)). This study continued with male rat pups obtained from both groups. Pups were sacrificed on postnatal day 21, and the heart tissues were extracted. Malondialdehyde, superoxide dismutase and catalase values were significantly higher in the experimental group rats, while glutathione values were lower. Light microscopy revealed irregularities in heart muscle fibers and apoptotic changes in the experimental group. Electron microscopy revealed crista loss and swelling in the mitochondria, degeneration in myofibrils and structural impairments in Z bands. Our study results suggest that exposure to EMF in the prenatal period causes oxidative stress and histopathological changes in male rat pup heart tissue.

Türedi S, Hancı H, Çolakoğlu S, Kaya H, Odacı E. Disruption of the ovarian follicle reservoir of prepubertal rats following prenatal exposure to a continuous 900-MHz electromagnetic field. Int J Radiat Biol. 92(6):329-337, 2016.

The effects on human health of electromagnetic field (EMF) have begun to be seriously questioned with the entry into daily life of devices establishing EMF, such as cell phones, wireless fidelity, and masts. Recent studies have reported that exposure to EMF, particularly during pregnancy, affects the developing embryo/fetus. The aim of this study was therefore to examine the effects of exposure to continuous 900-Megahertz (MHz) EMF applied in the prenatal period on ovarian follicle development and oocyte differentiation. Six pregnant Sprague Dawley rats were divided equally into a non-exposed control group (CNGr) and a group (EMFGr) exposed to continuous 900-MHz EMF for 1 h daily, at the same time every day, on days 13-21 of pregnancy. New groups were established from pups obtained from both groups after birth. One group consisting of female pups from CNGr rats was adopted as newborn CNGr (New-CNGr, n = 6), and another group consisting of female pups from EMFGr rats was adopted as newborn EMFGr (New-EMFGr, n = 6). No procedure was performed on New-CNGr or New-EMFGr rats. All rat pups were sacrificed on the postnatal 34th day, and their ovarian tissues were removed. Follicle count, histological injury scoring and morphological assessment with apoptotic index criteria were performed with sections obtained following routine histological tissue preparation. Follicle count results revealed a statistically significant decrease in primordial and tertiary follicle numbers in New-EMFGr compared to New-CNGr ($p < 0.05$), while atretic follicle numbers and apoptotic index levels increased significantly ($p < 0.05$). Histopathological examination revealed severe follicle degeneration, vasocongestion, a low level of increased stromal fibrotic tissue and cytoplasmic vacuolization in granulosa cell in New-EMFGr. Prenatal exposure to continuous 900-MHz EMF for 1 hour each day from days 13-21 led to a decrease in ovarian follicle reservoirs in female rat pups at the beginning of the prepubertal period.

Türedi S, Kerimoğlu G, Mercantepe T, Odacı E. Biochemical and pathological changes in the male rat kidney and bladder following exposure to continuous 900-MHz electromagnetic field on postnatal days 22-59. Int J Radiat Biol. 93(9):990-999, 2017.

PURPOSE: To investigate the effect on male rat kidney and bladder tissues of exposure to 900-megahertz (MHz) electromagnetic field (EMF) applied on postnatal days 22-59, inclusive. **MATERIALS AND METHODS:** Twenty-four male Sprague Dawley rats, aged 21 days, were used. These were divided equally into one of three groups, control (CG), sham (SG) or EMF (EMFG). CG was not exposed to any procedure. SG rats were kept inside a cage, without being exposed to the effect of EMF, for 1 h a day on postnatal days 22-59, inclusive. EMFG rats were exposed to continuous 900-MHz EMF for 1 h a day under the same conditions as those for the SG rats. Rats were sacrificed on postnatal day 60, and the kidney and bladder tissues were removed. Tissues were stained with hematoxylin and eosin (H&E) and Masson trichrome for histomorphological evaluation. The TUNEL method was used to assess apoptosis. Transmission electron microscopy (TEM) was also used for the kidney tissue. Oxidant/antioxidant parameters were studied in terms of biochemical values. **RESULTS:** The findings showed that tissue malondialdehyde increased in EMFG compared to CG and SG in both kidney ($p = 0.004$ and

p = 0.004, respectively) and bladder tissue (p = 0.004, p = 0.006, respectively), while catalase and glutathione levels decreased compared to CG (p = 0.004; p = 0.004, respectively) and SG (p = 0.004; p = 0.004, respectively). In the EMF group, pathologies such as dilatation and vacuolization in the distal and proximal tubules, degeneration in glomeruli and an increase in cells tending to apoptosis were observed in kidney tissue. In bladder tissue, degeneration in the transitional epithelium and stromal irregularity and an increase in cells tending to apoptosis were observed in EMFG. Additionally, EMFG samples exhibited glomerular capillary degeneration with capillary basement membranes under TEM. **CONCLUSIONS:** We conclude that continuous exposure to the effect of 900-MHz EMF for 1 h a day on postnatal days 22-59, inclusive, causes an increase in oxidative stress and various pathological changes in male rat kidney and bladder tissues.

Upadhyaya, C., Upadhyaya, T., Patel, I. Attributes of non-ionizing radiation of 1800 MHz frequency on plant health and antioxidant content of tomato (Solanum lycopersicum) plants. J Rad Res Appl Sci. 15:54-68, 2022.

The Globe is marching towards the development of the telecommunication field which leads to increment of non-ionizing radiation in the environment which affects all living beings including plants grown nearby to communication base stations. The present research was focused on physiological and biochemical alterations of tomato plants exposed to high-frequency radiation. The overall plant health was analyzed by physiological changes viz., plant height, size of leaves, length to the root system, and rate of germination upon exposure of radiation and shown significant reduction ($p < 0.05$) compared to control. Consecutively, radiation also negatively affects the photosynthetic pigment content of leaves which has shown significant reduction. Yet another confirmation of stress on exposed plant tissue was reported by obtaining higher H_2O_2 content within exposed plant leaf than the control. The morphological alterations viz. curling of leaves, discoloration, and size reduction became more prominent with an increase in the exposure time. The significant outcomes denoted according to 95% confidence limit. There was a significant decline in total phenolic content (37.06%), flavonoid content (71.38%), Vitamin C content (72.45%), and DPPH (59.32%) as well as total antioxidant assays (71.89%) which revealed significant deteriorative effects on such waves on secondary metabolites and the antioxidant potential of tomato plants. The lycopene content was continuously increasing up to 73.13% upon radiation of 120 h and such raise was the direct indication of harmful effect on fruit skin and release of lycopene due to softening of the fruit tissue. Thus, the presented findings illustrated the negative effects of such waves on the quality of tomato plants. The limited insight of metabolic pathways involved in plant responses to such non-ionizing radiation makes such investigation worth in agricultural application. Additionally, mobile communication agencies should be informed and installation of base stations for mobile communication towers should be prohibited at agricultural lands.

Vafaei H, Kavari G, Izadi HR, Dorahi ZZ, Dianatpour M, Daneshparvar A, Jamhiri I. Wi-Fi (2.4 GHz) affects anti-oxidant capacity, DNA repair genes expression and, apoptosis in pregnant mouse placenta. Iran J Basic Med Sci 23(6):833-840, 2020.

Objective(s): The placenta provides nutrients and oxygen to embryo and removes waste products from embryo's blood. As far as we know, the effects of exposure to Wi-Fi (2.4 GHz) signals on

placenta have not been evaluated. Hence, we examined the effect of prenatal exposure to Wi-Fi signals on anti-oxidant capacity, expressions of CDKNA1, and GADD45a as well as apoptosis in placenta and pregnancy outcome. Materials and Methods: Pregnant mice were exposed to Wi-Fi signal (2.4 GHz) for 2 and 4 hr. Placenta tissues were examined to measure the MDA and SOD levels. To measure SOD, CDKNA1, GADD45a, Bax, and Bcl-2 expressions were compared by real-time PCR analysis. TUNEL assay was used to assess apoptosis in placenta tissues. The results were analyzed by one-way analysis of variance (ANOVA) using Prism version 6.0 software. Results: MDA and SOD levels had significantly increased in exposed Wi-Fi signal groups (*P*-value< 0.05). Also, quantitative PCR experiment showed that SOD mRNA expression significantly increased in Wi-Fi signal groups. The data showed that CDKN1A and GADD45a genes were increased in Wi-Fi groups (*P*-value<0.05). The quantitative PCR and the TUNEL assay showed that apoptosis increased in Wi-Fi groups (*P*-value<0.05). Conclusion: Our results provide evidence that Wi-Fi signals increase lipid peroxidation, SOD activity (oxidative stres), apoptosis and CDKN1A and GADD45a overexpression in mice placenta tissue. However, further experimental studies are warranted to investigate other genes and aspects of pregnancy to determine the role of Wi-Fi radiation on fertility and pregnancy.

Velizarov, S., Raskmark, P., Kwee, S. The effects of radiofrequency fields on cell proliferation are non-thermal. Bioelectrochem Bioenerg. 48:177-180, 1999.

The number of reports on the effects induced by radiofrequency (RF) electromagnetic fields and microwave (MW) radiation in various cellular systems is still increasing. Until now no satisfactory mechanism has been proposed to explain the biological effects of these fields. One of the current theories is that heat generation by RF/MW is the cause, in spite of the fact that a great number of studies under isothermal conditions have reported significant cellular changes after exposure to RF/MW. Therefore, this study was undertaken to investigate which effect MW radiation from these fields in combination with a significant change of temperature could have on cell proliferation. The experiments were performed on the same cell line, and with the same exposure system as in a previous work [S. Kwee, P. Raskmark, Changes in cell proliferation due to environmental non-ionizing radiation: 2. Microwave radiation, Bioelectrochem. Bioenerg., 44 (1998), pp. 251-255]. The field was generated by signal simulation of the Global System for Mobile communications (GSM) of 960 MHz. Cell cultures, growing in microtiter plates, were exposed in a specially constructed chamber, a Transverse Electromagnetic (TEM) cell. The Specific Absorption Rate (SAR) value for each cell well was calculated for this exposure system. However, in this study the cells were exposed to the field at a higher or lower temperature than the temperature in the field-free incubator i.e., the temperature in the TEM cell was either 39 or 35 +/- 0.1 degrees C. The corresponding sham experiments were performed under exactly the same experimental conditions. The results showed that there was a significant change in cell proliferation in the exposed cells in comparison to the non-exposed (control) cells at both temperatures. On the other hand, no significant change in proliferation rate was found in the sham-exposed cells at both temperatures. This shows that biological effects due to RF/MW cannot be attributed only to a change of temperature. Since the RF/MW induced changes were of the same order of magnitude at both temperatures and also comparable to our previous results under isothermal conditions at 37 degrees C, cellular stress caused by electromagnetic fields could initiate the changes in cell cycle reaction rates. It is widely accepted that certain classes of heat-shock proteins are involved in these stress reactions.

Veyret, B., Bouthet, C., Deschaux, P., de Seze, R., Geffard, M., Joussot-Dubien, J, Le Diraison, M., Moreau, J.M., Caristan A. Antibody responses of mice exposed to low-power microwaves under combined, pulse-and-amplitude modulation. Bioelectromagnetics. 12:47-56, 1991.

Irradiation by pulsed microwaves (9.4 GHz, 1 microsecond pulses at 1,000/s), both with and without concurrent amplitude modulation (AM) by a sinusoid at discrete frequencies between 14 and 41 MHz, was assessed for effects on the immune system of Balb/C mice. The mice were immunized either by sheep red blood cells (SRBC) or by glutaric-anhydride conjugated bovine serum albumin (GA-BSA), then exposed to the microwaves at a low rms power density (30 microW/cm2; whole-body-averaged SAR approximately 0.015 W/kg). Sham exposure or microwave irradiation took place during each of five contiguous days, 10 h/day. The antibody response was evaluated by the plaque-forming cell assay (SRBC experiment) or by the titration of IgM and IgG antibodies (GA-BSA experiment). In the absence of AM, the pulsed field did not greatly alter immune responsiveness. In contrast, exposure to the field under the combined-modulation condition resulted in significant, AM-frequency-dependent augmentation or weakening of immune responses.

Wang J, Dong J, Xu Q, Yan S, Wang H, Lei H, Ma X, Yang T, Wang K, Li Z, Wang X. Melatonin ameliorates RF-EMR-induced reproductive damage by inhibiting ferroptosis through Nrf2 pathway activation. Pathol Res Pract. 270:156003, 2025. (average SAR 0.3 W/kg used in analysis)

In recent years, there has been increased attention to the deleterious impacts of radiofrequency electromagnetic radiation (RF-EMR) on male reproductive ability, necessitating the exploration of effective protective measures. Melatonin has antioxidant and anti-apoptotic effects, and there is growing evidence of its benefit to the reproductive process. However, the biochemical mechanisms by which melatonin protects against reproductive damage from RF-EMR exposure are unknown. Here, we found that prolonged (8 weeks) exposure to RF-EMR [2.45 GHz; power density, 2.5 W/m^2; whole-body specific absorption rate (SAR), 0.125–0.5 W/kg] induced ferroptosis and oxidative stress in testicular tissue, leading to a decrease of sperm quality in male mice. Notably, the administration of melatonin mitigated the oxidative harm to the testicles and ferroptosis caused by RF-EMR in mice. Mechanistically, melatonin could inhibit ROS production and ferroptosis by stimulating the nuclear factor-erythroid 2-related factor 2 (Nrf2) signaling pathway through its receptors (MT1/MT2). Taken together, these results indicate that melatonin could potentially improve RF-EMR-induced reproductive damage in male mice by blocking ferroptosis through activation of the Nrf2 pathway.

Wang XW, Ding GR, Shi CH, Zeng LH, Liu JY, Li J, Zhao T, Chen YB, Guo GZ. Mechanisms involved in the blood-testis barrier increased permeability induced by EMP. Toxicology. 276(1):58-63, 2010.

Blood-testis barrier (BTB) plays an important role in male reproductive system. Lots of environmental stimulations can increase the permeability of BTB and then result in antisperm antibody (AsAb) generation, which is a key step in male immune infertility. Here we reported the results of male mice exposed to electromagneticpulse (EMP) by measuring the expression of

tight-junction-associated proteins (ZO-1 and Occludin), vimentin microfilaments, and transforming growth factor-beta (TGF-beta3) as well as AsAb level in serum. Male BALB/c mice were sham exposed or exposed to EMP at two different intensities (200kV/m and 400kV/m) for 200 pulses. The testes were collected at different time points after EMP exposure. Immunofluorescence histocytochemistry, western blotting, laser confocal microscopy and RT-PCR were used in this study. Compared with sham group, the expression of ZO-1 and TGF-beta3 significantly decreased accompanied with unevenly stained vimentin microfilaments and increased serum AsAb levels in EMP-exposed mice. These results suggest a potential BTB injury and immune infertility in male mice exposed to a certain intensity of EMP.

Wang, Y., Jiang, Z., Zhang, L., Zhang, Z., Liao, Y., Cai, P. 3.5-GHz radiofrequency electromagnetic radiation promotes the development of Drosophila melanogaster. Environ Pollut. 294:118646, 2022.

With the rapidly increasing popularity of 5G mobile technology, the effect of radiofrequency radiation on human health has caused public concern. This study explores the effects of a simulated 3.5 GHz radiofrequency electromagnetic radiation (RF-EMF) environment on the development and microbiome of flies under intensities of 0.1 W/m^2, 1 W/m^2 and 10 W/m^2. We found that the pupation percentages in the first 3 days and eclosion rate in the first 2 days were increased under exposure to RF-EMF, and the mean development time was shortened. In a study on third-instar larvae, the expression levels of the heat shock protein genes hsp22, hsp26 and hsp70 and humoral immune system genes AttC, TotC and TotA were all significantly increased. In the oxidative stress system, DuoX gene expression was decreased, sod2 and cat gene expression levels were increased, and SOD and CAT enzyme activity also showed a significant increase. According to the 16S rDNA results, the diversity and species abundance of the microbial community decreased significantly, and according to the functional prediction analysis, the genera Acetobacter and Lactobacillus were significantly increased. In conclusion, 3.5 GHz RF-EMF may enhance thermal stress, oxidative stress and humoral immunity, cause changes in the microbial community, and regulate the insulin/TOR and ecdysteroid signalling pathways to promote fly development.

Wang Y, Zhang Z, Zhang L, Liao Y, Cai P. 3.5GHz radiofrequency electromagnetic fields (RF-EMF) on metabolic disorders in Drosophila melanogaster. Ecotoxicol Environ Saf. 304:119132, 2025.

The widespread implementation of fifth-generation (5 G) technology has raised concerns regarding its impact on biosafety. This study aims to uncover metabolic alterations in Drosophila melanogaster in response to electromagnetic radiation through metabolomics under 3.5 GHz radiofrequency electromagnetic fields (RF-EMF) conditions. Newborn male flies were continuously exposed to 3.5 GHz RF-EMF at intensities of 0.1 W/m^2, 1 W/m^2, and 10 W/m^2 throughout their entire life cycle under 24-hour constant darkness. Metabolomic analysis was performed on Drosophila samples after long-term exposure. The results indicate that long-term exposure to RF-EMF leads to disruptions in four metabolic pathways - alanine, aspartate and glutamate metabolism, tryptophan metabolism, ascorbate and aldehyde metabolism, and purine metabolism - as well as 34 differential metabolites across various power density in Drosophila melanogaster. Notably, the most significant metabolites (GABA, glucose-6-phosphate, AMP, N-formylglycinamide nucleotide, LPC, and MG) exhibited high sensitivity to

RF-EMF showing significant decreases. The suggests that long-term exposure to electromagnetic wave treatment may reduce the overall metabolic levels in fruit fly. These findings provide valuable insights into the metabolic disturbance induced by RF-EMF and enhance our understanding of the potential health effects associated with 5 G radiation.

Wen X, Rui X, Caiyun F, Chunyu Y, Haiyan C, Yi C. 900 MHz radiofrequency field induces mitochondrial unfolded protein response in mouse bone marrow stem cells. Frontiers in Public Health. 9:1265, 2021.

Objective: To examine whether exposure of mouse bone marrow stromal cells (BMSC) to 900 MHz radiofrequency fields used in mobile communication devices can induce mitochondrial unfolded protein response (UPR) Methods: BMSCs were exposed to continuous wave 900 MHz radiofrequency fields (RF) at 120 μW/cm^2 power intensity for 4 h/d for 5 consecutive days. Cells in sham group (SH) were cultured in RF exposure system, but without RF radiation. The positive control cells were irradiated with 6 Gy X-ray at a dose rate of 1.103 Gy/min (XR). To inhibit the upstream molecular JNK2 of UPR, cells in siRNA + RF, and siRNA + XR group were also pretreated with 100 nM siRNA-JNK2 for 48 h before RF/XR exposure. Thirty minutes, 4 h, and 24 h post-RF/XR exposure, cells were collected, the level of ROS was measured with flow cytometry, the expression levels of UPR-related proteins were detected using western blot analysis.Results: Compared with Sham group, the level of ROS in RF and XR group was significantly increased 30 min and 4 h post-RF/XR exposure ($P < 0.05$), however, the RF/XR-induced increase of ROS level reversed 24 h post-RF/XR exposure. Compared with Sham group, the expression levels of HSP10/HSP60/ClpP proteins in cells of RF and XR group increased significantly 30 min and 4 h post-RF/XR exposure ($P < 0.05$), however, the RF/XR-induced increase of HSP10/HSP60/ClpP protein levels reversed 24 h post-RF exposure. After interfering with siRNA-JNK2, the RF/XR exposures could not induce the increase of HSP10/HSP60/ClpP protein levels any more. Conclusions: The exposure of 900 MHz RF at 120 μW/cm^2 power flux density could increase ROS level and activate a transient UPR in BMSC cells. Mitochondrial homeostasis in term of protein folding ability is restored 24 h post-RF exposure. Exposure to RF in our experimental condition did not cause permanent and severe mitochondrial dysfunctions. However, the detailed underlying molecular mechanism of RF-induced UPR remains to be further studied.

Wolke, S., Neibig, U., Elsner, R., Gollnick, F., Meyer, R. Calcium homeostasis of isolated heart muscle cells exposed to pulsed high-frequency electromagnetic fields. Bioelectromagnetics. 17:144-153, 1996.

The intracellular calcium concentration ([Ca(2+)]i) of isolated ventricular cardiac myocytes of the guinea pig was measured during the application of pulsed high-frequency electromagnetic fields. The high-frequency fields were applied in a transverse electromagnetic cell designed to allow microscopic observation of the myocytes during the presence of the high-frequency fields. The [Ca(2+)]i was measured as fura-2 fluorescence by means of digital image analysis. Both the carrier frequency and the square-wave pulse-modulation pattern were varied during the experiments (carrier frequencies: 900, 1,300, and 1,800 MHz pulse modulated at 217Hz with 14 percent duty cycle; pulsation pattern at 900 MHz: continuous wave, 16 Hz, and 50 Hz modulation with 50 percent duty cycle and 30 kHz modulation with 80 percent duty cycle). The

mean specific absorption rate (SAR) values in the solution were within one order of magnitude of 1 mW/kg. They varied depending on the applied carrier frequency and pulse pattern. The experiments were designed in three phases: 500 s of sham exposure, followed by 500 s of field exposure, then chemical stimulation without field. The chemical stimulation (K+ -depolarization) indicated the viability of the cells. The K+ depolarization yielded a significant increase in [Ca(2+)]i. Significant differences between sham exposure and high-frequency field exposure were not found except when a very small but statistically significant difference was detected in the case of 900 MHz/50 Hz. However, this small difference was not regarded as a relevant effect of the exposure.

Xie, W., Xu, R, Fan, C., Yang, C., Chen, H., Cao, Y. 900 MHz radiofrequency field induces mitochondrial unfolded protein response in mouse bone marrow stem cells. Front. Public Health. 9:724239, 2021.

Objective: To examine whether exposure of mouse bone marrow stromal cells (BMSC) to 900 MHz radiofrequency fields used in mobile communication devices can induce mitochondrial unfolded protein response (UPR^{mt}). **Methods:** BMSCs were exposed to continuous wave 900 MHz radiofrequency fields (RF) at 120 $\mu W/cm^2$ power intensity for 4 h/d for 5 consecutive days. Cells in sham group (SH) were cultured in RF exposure system, but without RF radiation. The positive control cells were irradiated with 6 Gy X-ray at a dose rate of 1.103 Gy/min (XR). To inhibit the upstream molecular JNK2 of UPR^{mt}, cells in siRNA + RF, and siRNA + XR group were also pretreated with 100 nM siRNA-JNK2 for 48 h before RF/XR exposure. Thirty minutes, 4 h, and 24 h post-RF/XR exposure, cells were collected, the level of ROS was measured with flow cytometry, the expression levels of UPR^{mt}-related proteins were detected using western blot analysis. **Results:** Compared with Sham group, the level of ROS in RF and XR group was significantly increased 30 min and 4 h post-RF/XR exposure ($P < 0.05$), however, the RF/XR-induced increase of ROS level reversed 24 h post-RF/XR exposure. Compared with Sham group, the expression levels of HSP10/HSP60/ClpP proteins in cells of RF and XR group increased significantly 30 min and 4 h post-RF/XR exposure ($P < 0.05$), however, the RF/XR-induced increase of HSP10/HSP60/ClpP protein levels reversed 24 h post-RF exposure. After interfering with siRNA-JNK2, the RF/XR exposures could not induce the increase of HSP10/HSP60/ClpP protein levels any more. **Conclusions:** The exposure of 900 MHz RF at 120 $\mu W/cm^2$ power flux density could increase ROS level and activate a transient UPR^{mt} in BMSC cells. Mitochondrial homeostasis in term of protein folding ability is restored 24 h post-RF exposure. Exposure to RF in our experimental condition did not cause permanent and severe mitochondrial dysfunctions. However, the detailed underlying molecular mechanism of RF-induced UPR^{mt} remains to be further studied.

Xu Y, Zheng ZA, Zhu T, Zhu B, Feng C, Chen Y, Qin F. [Joint effects of nano-selenium and nano-cerium on the male reproductive function of mice exposed to microwave radiation] Wei Sheng Yan Jiu 49(5):795-801, 2020. [Article in Chinese]

Objective: To study effect of nano-selenium and nano-cerium(nano cerium oxide) on the spermatogenic ability of mice irradiated by 1800 MHz microwave radiation(MR).
Methods: Forty-two ICR mice were randomly divided into groups: blank control group, solvent

control group, microwave radiation model group, low, medium and high dose groups of nano-selenium+nano-cerium. In joint effects groups of nano-selenium and nano-cerium, the nano-selenium solution(60, 120 and 240 μg/kg) and the nano-cerium oxide solution(15, 30, 60 μg/kg) were administered to the stomach at 7:30 in the morning and 18:30 in the evening, respectively. The blank control group was orally administered with an equal volume of distilled water, and the solvent control group and the MR group were orally administered with an equal volume of carboxymethylcellulose sodium solution. During the second week of gastric administration, the mice were exposed to microwave radiation(1800 MHz) for 2 h every day(specific absorption ratio: 0. 2986 W/kg). After MR treatment, the daily sperm production of testis, sperm motility and sperm deformity rate in epididymis were measured, and the testicular marker enzymes [G6 PDH(6-phosphatedehydrogenase), ACP(acid phosphatase), LDH(lactate dehydrogenase)], antioxidant indexes [CAT(catalase), MDA(malondialdehyde) and T-AOC(total antioxidant capacity)] in testicular tissue were analyzed. **Results:** Compared with the solvent control group, MR led to the decrease of sperm motility and the increase of sperm deformity rate, decreased the enzymes activities of G6 PDH, ACP and CAT, increased LDH activity and MDA content, and decreased the T-AOC level in testicular tissue, and the differences were statistically significant(P< 0. 05). Compared with the MR group, the joint action of nano-selenium and nano-cerium with medium dose increased the daily sperm production of testis((18. 98±1. 27) ×10~6/g) vs. (15. 53±1. 24) ×10~6/g), decreased the sperm deformity rate(11. 74%±0. 91% vs. 16. 84%±2. 05%), and the joint action of nano-selenium and nano-cerium with medium and high dose increased the sperm motility in epididymis(61. 98%±6. 33%, 54. 17±4. 38 vs. 45. 16%±5. 01%), and the differences were statistically significant(P<0. 05). Compared with the MR group, the joint action of nano-selenium and nano-cerium with low and medium dose increased the activity of ACP(11. 07±0. 98, 14. 85±1. 39 vs. 8. 72±0. 91 nmol/(min·mg prot), P<0. 05). The joint action of nano-selenium and nano-cerium with medium and high dose increased the activity of G6 PDH(24. 12±2. 06, 21. 36±3. 65 vs. 15. 11±1. 73 nmol/(min·mg prot), P<0. 05) and decreased the activity of LDH(15. 52±1. 17, 13. 51±1. 68 vs. 22. 46±2. 01 nmol/(min·mg prot), P<0. 05). The joint action of nano-selenium and nano-cerium with medium dose increased the activity of CAT(17. 92±2. 03 vs. 11. 69±0. 87 nmol/(min·mg prot), P<0. 05) and decreased the content of MDA(5. 17 ±0. 62 vs. 9. 03 ±0. 63 nmol/mg prot, P<0. 05). The joint action of nano-selenium and nano-cerium with low, medium and high dose increased the level of T-AOC(22. 06±1. 54, 29. 36±2. 39, 21. 01±2. 47 vs. 12. 88±1. 82 U/mg prot, P<0. 05). **Conclusion:** The joint addition of nano-selenium and nano-cerium can improve the reproductive function of male mice exposed to MR, and can effectively alleviate the changes of mouse testicular marker enzyme activity and the decline of antioxidant capacity caused by MR.

Yavas MC, Kilitci A, Çelik E, Yegin K, Sirav B, Varol S. Rat brain and testicular tissue effects of radiofrequency radiation exposure: Histopathological, DNA damage of brain and qRT-PCR analysis. INTERNATIONAL JOURNAL OF RADIATION RESEARCH. 22(3):529-536, 2024.

We evaluate the effects of radiofrequency electromagnetic field (RF-EMF) on rat brain and testicular tissue using histopathology, comet assay, and real-time quantitative PCR techniques. Materials and Methods: Two equal groups of fourteen rats one for sham-control and the other for exposure (n = seven) were created. For a duration of 14 days, the exposure group (2100 MHz, testicular tissue SAR values of 163 mW/kg for 10 g, brain tissue SAR values of 292 mW/ kg on

average) was subjected to five hours of exposure per day. Evaluations were conducted on tissue gene expression levels, histopathology, and DNA damage to brain tissue. Results: The histological examination of brain tissue from the exposed group revealed vascular alterations and significant edema ($p < 0.05$). It was determined that RF radiation-induced much more cellular damage in the exposed group (18.26% tail DNA) than in the control group (4.06% tail DNA). Signs of deterioration in spermatogenic cells in the testicular tissue of the exposed group also changed significantly ($p < 0.05$). The Bax and bcl-2 genes showed a significant difference ($p < 0.05$) in the mRNA level data, whereas the p53 genes showed no significant change ($p > 0.05$). Conclusion: These findings suggest that it may cause some histopathological and cellular damage in brain and testis tissue.

Yilmaz A, Tumkaya L, Akyildiz K, Kalkan Y, Bodur AF, Sargin F, Efe F, Uydu HA, Yazici ZA. Lasting hepatotoxic effects of prenatal mobile phone exposure. J Matern Fetal Neonatal Med 30(11):1355-1359, 2017.

Objective: In this study, the livers of rats born to mothers exposed to electromagnetic field (EMF) were examined 60 days postpartum for biochemical and histopathological changes. **Methods:** Pregnant rats were exposed to radiation (900 MHz EMF, 24 h/day for 20 days) using a digital signal generator by placing the device centrally under the cage, which formed the study (EMF) group, while untreated matching rats served as controls. Livers and blood were obtained from litters (seven males and seven females) of both groups 60 days after birth, which were used for biochemical and histopathological analyses. **Results:** There was a significant increase in the levels of malondialdehyde (MDA) ($p < 0.05$) that was accompanied by a significant fall in glutathione (GSH) ($p < 0.01$) in the liver. The serum levels of alanine aminotransferase (ALT) and aspartate aminotransferase (AST) were significantly increased ($p < 0.05$). Histopathologically, the liver sections of the EMF group showed intense degeneration in hepatocytes with cytoplasmic eosinophilic structures, pyknotic nuclei and fibrosis. **Conclusion:** We demonstrate that the intrauterin harmful effects of EMF on the livers of rats persist into adulthood.

Yilmaz H, Tümkaya L, Mercantepe T, Yılmaz A, Gül F, Suzan ZT. Effects of 5G mobile phone network electromagnetic field exposure on testicular endoplasmic reticulum stress and the protective role of coenzyme Q10. Arch Med Res. 56(4):103157, 2025.

Aim: Nowadays, the electromagnetic field (EMF) has become an issue of electromagnetic pollution. This study aimed to determine the effect of 5 G Fr1 frequency band EMF waves on endoplasmic reticulum (ER) stress in testicular tissue and to demonstrate the efficacy of coenzyme Q10 (CoQ10) in suppressing the potential situation. Materials and methods: Three groups of eight male Sprague-Dawley rats were established. In group I (control) received only saline solution by oral gavage. In group II (EMF), saline solution was administered by oral gavage and the rats were exposed to 5.9 GHz EMF for 2 h/d (09:00-11:00). In group III (EMF+ CoQ10), the EMF exposure was created in the same way as in group II and CoQ10 was given daily at 10 mg/kg (CoQ10), 2 mg/kg dissolved in corn oil and administered by oral gavage for the experimental period (30 days). Results: Histopathological damage, including edematous

regions, vascular congestion, and neutrophil inflammation accompanied by loss of spermatogenic cells, particularly spermatozoa, and spermatids, increased thiobarbituric acid (TBARS) and decreased total thiol (TT) levels were observed in the seminiferous tubules in the EMF group. Furthermore, germinal epithelial cells showing intense GRP-78 immunopositivity and spermatogenic cells indicating C/EBP homologous protein (CHOP) immunopositivity were increased in the seminiferous tubules. On the other hand, in the EMF+CoQ10 group, both histopathological and biochemical findings were observed in the opposite direction. Conclusion: Due to its antioxidant properties and its ability to suppress oxidative stress and apoptosis, CoQ10 may be a promising candidate against 5 G EMF-induced testicular ER damage.

Yilmaz H, Tumkaya L, Mercantepe T, Gül F, Karakas S. The neuroprotective role of coenzyme Q10 against endoplasmic reticulum stress in the olfactory bulb caused by 5 G electromagnetic field exposure. Tissue Cell. 2026 Mar 30;101:103510. doi: 10.1016/j.tice.2026.103510. Epub ahead of print.

The widespread use of 5 G mobile communication technology has raised the possibility of neurosensory effects arising from exposure to electromagnetic fields (EMF). This study investigated the effects of EMF exposure in the 5 G FR1 band on the olfactory bulb and the potential protective role of coenzyme Q10 (CoQ10). Male Sprague-Dawley rats were randomly divided into three groups. Group 1 (Control) received only saline via oral gavage. Group 2 (EMF) was exposed to EMF in the 5 G FR1 band for 2 h per day (09:00-11:00) and received oral saline. Group 3 (EMF + CoQ10) underwent the same EMF exposure and additionally received 10 mg/kg CoQ10 dissolved in corn oil at 2 mg/kg orally for 30 days. At the end of the experiment, olfactory bulb tissue samples were collected from all animals. Tissue sections were stained with hematoxylin-eosin (H&E) and evaluated histopathologically. Endoplasmic reticulum (ER) stress levels were analyzed by immunohistochemical methods based on GRP78 and CHOP expression. Oxidative stress parameters, malondialdehyde (MDA) and glutathione (GSH) levels, were measured in the tissue (mg/g) using biochemical methods. In the EMF group, prominent histopathological changes such as widespread glial cell abnormalities, inflammation, necrotic neurons with pyknotic nuclei, and neuronal degeneration were observed in the olfactory bulb tissue. In this group, the expressions of GRP78 and CHOP, which are markers of ER stress, and MDA levels, which are indicators of oxidative stress, were significantly increased compared to the control group, while GSH levels were decreased. In contrast, in the EMF + CoQ10 group, these adverse changes were significantly reduced, histopathological damage was significantly decreased, GRP78 and CHOP expression levels were reduced, MDA levels showed a downward trend, and GSH levels increased significantly, approaching those of the control group ($p < 0.05$). It was demonstrated that EMF exposure in the 5 G FR1 band causes ER stress and oxidative damage in the olfactory bulb tissue, while CoQ10 may play a protective role by reducing these harmful effects.

Yüksel M, Nazıroğlu M, Özkaya MO. Long-term exposure to electromagnetic radiation from mobile phones and Wi-Fi devices decreases plasma prolactin, progesterone, and estrogen levels but increases uterine oxidative stress in pregnant rats and their offspring. Endocrine. 52(2):352-362, 2016.

We investigated the effects of mobile phone (900 and 1800 MHz)- and Wi-Fi (2450 MHz)-induced electromagnetic radiation (EMR) exposure on uterine oxidative stress and plasma hormone levels in pregnant rats and their offspring. Thirty-two rats and their forty newborn offspring were divided into the following four groups according to the type of EMR exposure they were subjected to: the control, 900, 1800, and 2450 MHz groups. Each experimental group was exposed to EMR for 60 min/day during the pregnancy and growth periods. The pregnant rats were allowed to stand for four generations (total 52 weeks) before, plasma and uterine samples were obtained. During the 4th, 5th, and 6th weeks of the experiment, plasma and uterine samples were also obtained from the developing rats. Although uterine lipid peroxidation increased in the EMR groups, uterine glutathione peroxidase activity (4th and 5th weeks) and plasma prolactin levels (6th week) in developing rats decreased in these groups. In the maternal rats, the plasma prolactin, estrogen, and progesterone levels decreased in the EMR groups, while the plasma total oxidant status, and body temperatures increased. There were no changes in the levels of reduced glutathione, total antioxidants, or vitamins A, C, and E in the uterine and plasma samples of maternal rats. In conclusion, although EMR exposure decreased the prolactin, estrogen, and progesterone levels in the plasma of maternal rats and their offspring, EMR-induced oxidative stress in the uteri of maternal rats increased during the development of offspring. Mobile phone- and Wi-Fi-induced EMR may be one cause of increased oxidative uterine injury in growing rats and decreased hormone levels in maternal rats. TRPV1 cation channels are the possible molecular pathways responsible for changes in the hormone, oxidative stress, and body temperature levels in the uterus of maternal rats following a year-long exposure to electromagnetic radiation exposure from mobile phones and Wi-Fi devices. It is likely that TRPV1-mediated Ca^{2+} entry in the uterus of pregnant rats involves accumulation of oxidative stress and opening of mitochondrial membrane pores that consequently leads to mitochondrial dysfunction, substantial swelling of the mitochondria with rupture of the outer membrane and release of oxidants such as superoxide (O_2^-) and hydrogen peroxide (H_2O_2). The superoxide radical is converted to H_2O_2 by superoxide dismutase (SOD) enzyme. Glutathione peroxidase (GSH-Px) is an important antioxidant enzyme for removing lipid hydroperoxides and hydrogen peroxide and it catalyzes the reduction of H_2O_2 to water.

Yurekli, A.I., Ozkan, M., Kalkan, T., Saybasili, H., Tuncel, H., Atukeren, P., Gumustas, K., Seker, S. GSM base station electromagnetic radiation and oxidative stress in rats. Electromagn Biol Med. 25:177-188, 2006.

The ever increasing use of cellular phones and the increasing number of associated base stations are becoming a widespread source of nonionizing electromagnetic radiation. Some biological effects are likely to occur even at low-level EM fields. In this study, a gigahertz transverse electromagnetic (GTEM) cell was used as an exposure environment for plane wave conditions of far-field free space EM field propagation at the GSM base transceiver station (BTS) frequency of 945 MHz, and effects on oxidative stress in rats were investigated. When EM fields at a power density of 3.67 W/m2 (specific absorption rate = 11.3 mW/kg), which is well below current exposure limits, were applied, MDA (malondialdehyde) level was found to increase and GSH (reduced glutathione) concentration was found to decrease significantly ($p < 0.0001$). Additionally, there was a less significant ($p = 0.0190$) increase in SOD (superoxide dismutase) activity under EM exposure.

Zeni O, Sannino A, Romeo S, Massaa R, Sarti M, Reddy AB, et al. Induction of an adaptive response in human blood lymphocytes exposed to radiofrequency fields: Influence of the universal mobile telecommunication system (UMTS) signal and the specific absorption rate. Mutat Res. 747: 29-35, 2012.

The induction of an adaptive response (AR) was examined in human peripheral blood lymphocytes exposed to non-ionizing radiofrequency fields (RF). Cells from nine healthy human volunteers were stimulated for 24h with phytohaemagglutinin and then exposed for 20h to an adaptive dose (AD) of a 1950MHz RF UMTS (universal mobile telecommunication system) signal used for mobile communications, at different specific absorption rates (SAR) of 1.25, 0.6, 0.3, and 0.15W/kg. This was followed by treatment of the cells at 48h with a challenge dose (CD) of 100ng/ml mitomycin C (MMC). Lymphocytes were collected at the end of the 72h total culture period. The cytokinesis-block method was used to record the frequency of micronuclei (MN) as genotoxicity end-point. When lymphocytes from six donors were pre-exposed to RF at 0.3W/kg SAR and then treated with MMC, these cells showed a significant reduction in the frequency of MN, compared with the cells treated with MMC alone; this result is indicative of induction of AR. The results from our earlier study indicated that lymphocytes that were stimulated for 24h, exposed for 20h to a 900MHz RF GSM (global system for mobile communication) signal at 1.25W/kg SAR and then treated with 100ng/ml MMC, also exhibited AR. These overall data suggest that the induction of AR depends on RF frequency, type of the signal and SAR. Further characterization of RF-induced AR is in progress.

Zong, C., Ji, Y., He, Q., Zhu, S., Qin, F., Tong, J., Cao, Y. Adaptive response in mice exposed to 900 MHz radiofrequency fields: Bleomycin-induced DNA and oxidative damage/repair. Int J Radiat Biol. 91: 270-276, 2015.

Purpose: To determine whether mice exposed to radiofrequency fields (RF) and then injected with a radiomimetic drug, bleomycin (BLM), exhibit adaptive response and provide some mechanistic evidence for such response. **Materials and methods:** Adult mice were exposed to 900 MHz RF at 120 μW/cm(2) power density for 4 hours/day for 7 days. Immediately after the last exposure, some mice were sacrificed while the others were injected with BLM 4 h later. In each animal: (i) The primary DNA damage and BLM-induced damage as well as its repair kinetics were determined in blood leukocytes; and (ii) the oxidative damage was determined from malondialdehyde (MDA) levels and the antioxidant status was assessed from superoxide dismutase (SOD) levels in plasma, liver and lung tissues. **Results:** There were no indications for increased DNA and oxidative damages in mice exposed to RF alone in contrast to those treated with BLM alone. Mice exposed to RF+ BLM showed significantly: (a) reduced BLM-induced DNA damage and that remained after each 30, 60, 90, 120 and 150 min repair time, and (b) decreased levels of MDA in plasma and liver, and increased SOD level in the lung. **Conclusions:** The overall data suggested that RF exposure was capable of inducing adaptive response and mitigated BLM- induced DNA and oxidative damages by activating certain cellular processes.

Zosangzuali M, Lalremruati M, Lalmuansangi C, Nghakliana F, Pachuau L, P, Siama Z. Effects of radiofrequency electromagnetic radiation emitted from a mobile phone base station on

the redox homeostasis in different organs of Swiss albino mice. Electromagn Biol Med 40:393-407, 2021.

This study was designed to investigate the possible effects of exposure to mobile phone base station (MPBS) emits 1800-MHz RF-EMR on some oxidative stress parameters in the brain, heart, kidney and liver of Swiss albino mice under exposures below thermal levels. Mice were randomly assigned to three experimental groups which were exposed to RF-EMR for 6 hr/day, 12 hr/day and 24 hr/day for 45 consecutive days, respectively, and a control group. The glutathione (GSH) levels and activities of glutathione-s-transferase (GST) and superoxide dismutase (SOD) were significantly reduced in mice brain after exposure to RF-EMR for 12 hr and 24 hr per day. Exposure of mice to RF-EMR for 12 hr and 24 hr per day also led to a significant increase in malondialdehyde (an index of lipid peroxidation) levels in mice brain. On the contrary, exposures used in this study did not induce any significant change in various oxidative stress-related parameters in the heart, kidney and liver of mice. Our findings showed no significant variations in the activities of aspartate amino-transferase (AST), alanine amino-transferase (ALT), and on the level of creatinine (CRE) in the exposed mice. This study also revealed a decrease in RBC count with an increase in WBC count in mice subjected to 12 hr/day and 24 hr/day exposures. Exposure to RF-EMR from MPBS may cause adverse effects in mice brain by inducing oxidative stress arising from the generation of reactive oxygen species (ROS) as indicated by enhanced lipid peroxidation, and reduced levels and activities of antioxidants.