Effect of Radiofrequencies Emitted from Mobile Phones and Wi-Fİ on Pregnancy

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Abstract

Wireless communication has become indispensable in our daily life due to the advent of mobile phone technologies. Radio frequencies (RFs) are a main parameter in wireless communication technology in order to provide data (audio, image, etc.) transfer. However, public concern is continuously increasing because of the results of scientific studies on the health effects of RF radiation emitted from these devices. Scientists recently pointed out that the most important risk groups are pregnant women and children. Therefore, the aim of this review is to summarize the animal RF studies performed on both pregnant women and their babies throughout the pregnancy period. The majority of the studies are based on animal studies and suggest that pregnant women, and thereby their babies, can be adversely affected by RF exposure. In conclusion, this review indicated that staying away from RF exposure during the pregnancy would be a wise precaution, at least until a clear scientific result is reached.

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Introduction

Many devices we use in our daily life (remote controls, microwave ovens, security systems, cell phones, computers, walkie-talkies, radars, TV and radio transmitters, Bluetooth, and wireless internet providers) emit radiofequency radiation (RFR). The RFR level formed by different wireless communication tools, and especially by cell phones, is increasing rapidly, causing a problem known as “Electromagnetic Pollution.” Results of studies on the effects of RF waves emitted by wireless communication sources have caused the International Agency for Research on Cancer, which is an important branch of the World Health Organization (WHO), to include RF radiation among 2B factors, which may be carcinogenic.[1]

Safety limits have been determined for the general public and employees by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and Institute of Electrical and Electronics Engineers (IEEE) for protection against the possible negative effects of RFR. However, more sensitive groups such as pregnant women, fetuses, or embryos have also been subject to the same safety limits. One of the substances that RFs are most effective on is water. It is reported that "high water content would effect dielectric values, which in turn would have an effect on energy absorption. However, fetus organs are not fully developed and their tissue composition is slightly different with high water content.[2] It means that, tissues with more water content are affected more by RFs. As it is known, the water content of women during pregnancy increases in comparison with normal periods. This is also the case for fetuses in the mother’s womb. It has been suggested that anomalies may develop in fetuses or embryos which interact with RF throughout the pregnancy period.[3,4] In addition, the sensitivities of children to electromagnetic fields were handled during a workshop organized in 2004 by in Istanbul as a result of which it was concluded that the number of relevant studies should be increased.[5]

In this review, animal studies on the effects of RFs on the pregnancy and fetus will be summarized. The number of animal studies on

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the effects of RF radiation emitted in to the environment by communication tools such as cell phones and wireless internet providers (Wi-Fi) on fetus and mothers is quite limited. There are differences between various parameters such as the experimental setups, techniques used, specific absorption rates, and so on. However, the majority of these studies are carried out on animals.

Animal studies

Dasdag et al. (2000), examined the effects of being subject to GSM RF radiation emitted from cell phones (900 MHz, 217 Hz modulation frequency, pulse width 577 µs) throughout a pregnancy on the peripheric blood parameters and fetal development in pregnant rats and their offspring. Pregnant rats were subject to RFR emitted from cell phones during the prenatal period for a period of one minute three times every two hours of standby position, every day. The results were that there was no determinable difference in the peripheric blood parameters (erythrocyte, leucocyte, lymphocyte count, hemoglobin, and hematocrit level) of either pregnant or normal rats subjected to RFR. In addition, the RF signals did not cause any abnormal situation during the pregnancy or in the pregnancy results. Only a decrease was observed in the birth weights of newborn rats.[6]

Guler et al. (2010) designed an experimental study to evaluate the effects of full body exposure to 1800 MHz GSM-like RF radiation on oxidative DNA damage in the brain and lipid peroxidation levels in pregnant and non-pregnant New Zealand white rabbits and their offspring. The RF signals used in the study were generated with amplitude modulation via rectangular pulses with a repetition frequency of 217 Hz and a 1:8 duty cycle (pulse width 0.576 ms) in accordance with the dominant modulation component of GSM. Some of the pregnant rabbits were subjected to these RF signals for 15 minutes every day over a period of seven days during the 15th and 22nd days of their pregnancy. These RF signals were also applied to another group of non-pregnant rabbits over seven days. Even though the highest safety limit values of full boxy exposure to 1800 MHz RF radiation as determined by ICNIRP is 58.3 V/m for the general public and 127.3 V/m for employees, the electrical field value generated by the RF signals used in this study were set to 14 V/m, which is much lower than the safety limit, because even though the current safety limits are based on the thermal effects that depend on acute exposure to RF radiation, people might be chronically subjected to these fields at non-thermal levels. It was determined as a result of the study that RF waves caused an oscillation of free radicals in the brain tissue of pregnant and non-pregnant rabbits and oxidative damage in lipid and DNA molecules. However, no change was observed in the analyzed parameters of newborns subject to RF radiation in the uterus.[7]

Tomruk et al. (2009) similarly carried out an experimental study on the effect of 1800 MHz signals on DNA damage due to free radical attacks in the liver tissues. The most striking result of this study was that RF signals induced harmful effects on the free radicals of membrane phospholipids, thus affecting increased MDA and FOX levels and lipid peroxidation in pregnant and non-pregnant rabbits. However, the formation of these radical molecules did not take place at a level that would cause oxidative DNA damage in liver tissue. No difference was observed in the livers of the offspring of the pregnant rabbits subject to RF radiation with regard to DNA base modification, free radical formation, and lipid peroxidation product levels.[8]

It is indicated that RFR exposure increase lipid peroxidation levels in both female and male liver tissues following RF radiation exposure. However, the 8-hydroxy-2 ’ -deoxyguanosine (8-OHdG) level, indicating DNA damage due to oxidative stress, increased in female offspring subject to RF radiation, yet remained constant in male offspring subject to RF radiation.[9]

De Gannes et al. (2009) carried out a study in which the effects of RF waves with continuous wave property generated under far field conditions at 2450 MHz frequency and 5 W/m^2 energy intensity were examined on the immunity, degenerative parameters, and prenatal development in freely moving female Wistar rats. The full body SAR value was indicated as 0.16 W/kg in the study. The rats were subjected to RF radiation with the aforementioned properties for a period of five days with seven hours exposure per day for a period of 30 days. Serums of blood samples were obtained from each rat at 7 and 14 days after exposure, after which the antigens determined specifically for neurodegenerative and autoimmune processes were examined via ELISA. One-milliliter blood serums taken from the rats that were subject to radiation were

administered on the 10th day of pregnancy, whereas blood samples were administered to rats that were not subject to RF radiation and no prenatal or postnatal adverse effects were observed.[10]

De Gannes et al. (2012) carried out another study in which the teratogenic effects of RF radiation of frequency 2450 MHz and SAR values of 0.08, 0.4, and 4 W/kg were examined. The pregnant rats in the study were subject to RF radiation levels accepted as public, occupational and critical exposure limits for a period of 18 days at two hours per day, six days per week. No teratogenic effect was observed during either the prenatal or the postnatal periods in pregnant and newborn rats subject to RF radiation. However, an increase in food consumption during the breastfeeding period was observed in pregnant rats subject to RFs with a SAR value of 0.4 W/kg.[11]

Ait-Aissa et al. (2010) examined the effects on the central nervous systems of young rats subject to Wi-Fi signals (2.45 GHz, SAR: 0, 0.08, 0.4, 4 W/kg) during the prenatal period (two hours/day, five days/week, from the sixth day to the 21st day of pregnancy, for two weeks) and the first weeks of the postnatal period (the first five weeks until the weaning period). The status of the apoptotic neurons in the brains of young rats were determined after which glial fibrillary acidic protein (GFAP) expression was examined to determine astrocyte effectiveness, because astroglial cells are activated as a result of triggering in the increase of GFAP expression due to damage in the central nervous system. It was put forth by the results obtained from the study that the Wi-Fi signals that were used caused no permanent astroglia activation in the brains of the young rats under the experiment conditions and that apoptosis was not triggered. Therefore, it can be stated that exposure to Wi-Fi signals during the prenatal period has no adverse effect in brain development.[12]

Another study examined the various immunological markers in rats subject to RF during the prenatal and postnatal periods. Pregnant Wistar rats moving freely in a cage were subject to 2450 MHz RF radiation during their free movement over a period of five days each week and two hours per day during the 6–21 days of their pregnancy. SAR values were as indicated by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) as safety limits; 0 W/kg (sham exposure), 0.08 W/kg (public exposure), 0.4 W/kg (occupational exposure), 4 W/kg (critical level) have been used. Some of the newborn offspring were subjected to RF radiation under the same conditions for 35 days during the postnatal period. All offspring were killed following final exposure and blood serums were collected. Antibody screening for 15 antigens that were selected for their relationship with damage and pathological processes was carried out on these serums. No SAR-dependent change was observed in the immunoglobulin levels of the serums of young rats subject to Wi-Fi, even though a wide variety of antigens were tested. In addition, no difference was observed in pregnant rats with regard to body mass, number of offspring per birth, and the body masses of offspring.[13]

Devices with wireless technology such as laptop computers and cell phones are generally carried near the kidneys and reproductive organs. The testes are particularly sensitive to oxidative damage induced by ROS and have a low amount of antioxidants.[14] It has been reported that the RFR emitted by Wi-Fi and cell phones can result in decreased antioxidant levels in the kidneys and testicles and can cause oxidative stress (15;16). Dasdag et al. indicated that long term exposure to 2.4 GHz RF radiation (Wi-Fi) does not cause DNA damage in organs (brain, liver, kidney, or skin) except the testes. They stated that the testes are more sensitive to RF radiation.[17] In light of this, Özorak et al. (2013) designed an experimental study to examine oxidative stress formation and trace elements in the kidneys and testicles of rats subject to the RFR emitted by Wi-Fi (2.45 GHz) and cell phones (900 and 1800 MHz) during the prenatal and postnatal period (until the 4th, 5th and 6th week). 2450 MHz, 900 MHz, and 1800 MHz RFR (0.18±0.07 W/kg SAR; 10 V/m) was applied to pregnant Wistar albino rats throughout their pregnancy and to male newborns immediately after birth until the 4th, 5th, and 6th weeks for 60 minutes per day five days per week. The kidneys and testicles of animals were removed following exposure to RF radiation and both oxidative stress indicators and trace element levels were examined. An increase was observed in the lipid peroxidation level and oxidizable iron content throughout the kidney and testicle development in addition to a decrease in the amounts of trace elements such as zinc and copper, total

antioxidant status (TAS) and glutathione (GSH) levels. Thus, it was put forth under the aforementioned experimental conditions that RF radiation from Wi-Fi and cell phones might cause early adolescence and oxidative damage in the kidneys of developing rats.[18]

It has been reported that electromagnetic fields prevent the formation and differentiation of neural stem cells during embryonic development while also inducing cell deaths[19] and the formation of granule cells, which are a basic cell type of the dentate gyrus in the hippocampus, continues throughout the postnatal period and ends on the 3rd week after birth.[20] Adverse effects to which subjects were exposed during pregnancy might be the cause for the hippocampal formations and both neurobiological and behavioral disorders in the offspring, because this region is very sensitive to disruptive effects.[21] Depending on this information, Odaci et al. (2008) examined the effects on the number of granule cells in the dentate gyrus of the offspring of Wistar albino rats subject to 900 MHz RF radiation with a continuous wave property. The average applied energy intensity was put forth as 1±0.4 mW/cm^2, whereas the highest SAR value was specified as 2 W/kg. Pregnant rats were subjected to RF radiation for a period of 60 minutes each day and the offspring were sacrificed four weeks after birth. The dentate gyrus granule cell numbers of the offspring were analyzed via an optical fractionator technique. Thus, it was put forth that the number of dentate gyrus granule cells in the hippocampus were decreased in the offspring of rats subjected to RF radiation throughout their pregnancy. Hence, exposure to 900 MHz RF radiation during the prenatal period may affect the development of dentate gyrus granule cells in the hippocampus of rats, which causes cell loss.[22]

Bas et al. (2009) examined the effects of 900 MHz RF radiation (average energy intensity 1±0.4 mW/cm^2 at the highest SAR value 2W/kg) on the pyramidal cells in the hippocampus of newborn rats. The brains of the offspring of Wistar albino rats that had been subjected to radiation for 60 minutes per day throughout pregnancy (between days 1–19) were removed when they were four weeks old, after which the Cornu Ammonis section of the hippocampus was analyzed. A statistically significant decrease was put forth in the total number of pyramidal cells in the rats that had been subjected to RF radiation compared to the rats in the control group as a result of the pyramidal cell count in the Cornu Ammonis via optical fractionator technique.[23]

Ragbetli et al. (2009) designed an experiment to examine the effects of exposure during the prenatal period to radiation emitted from cell phones on the number of hippocampal pyramidal cells in animals. Swiss albino rats were exposed to 890–915 MHz RF radiation (when the module was 1.2 W/kg SAR at a 217 Hz pulse repetition frequency) emitted from cell phones for a period of 15 minutes each day throughout their pregnancy. The hippocampal regions of the offspring of these rats were examined after removing their left hemisphere. No statistically significant difference was observed in the total number of pyramidal cells in the Cornu Ammonis regions in the hippocampus using the optical fractionator method.[24] It is also reported that significant decrease was determined in the Purkinje neurons in addition to a tendency in an increase in the number of granule cells in the cerebellum of the offspring of rats exposed to RFR.[25]

Bas et al. (2013) observed during the 13–21 days of the prenatal period that there were pyknotic cells in the Cornu Ammonis region of the hippocampus on the 32nd day of the postnatal period in Wistar albino rats subjected to RF radiation of RF 900 MHz (electrical field 10 V/m, average electrical field intensity 0.265 W/m^2) and that the number of pyramidal cells decreased at a statistically significant level in the group subject to radiation. They also put forth that exposure to RF radiation during the 13th–21st days of the prenatal period could cause cell deaths and thus decrease the number of pyramidal cells during the postnatal period.[26]

Haghani et al. (2013) set up an experimental study to determine the possible effects of exposure to RF radiation during the prenatal period on the cerebellum of Wistar rats. RF radiation with a 900 MHz pulse was applied to Wistar rats over a period of six days throughout their pregnancy. The measured SAR values varied in the 0.5–0.9 W/kg interval. All behavioral and electrophysiological tests were carried out on the offspring on the 30th and 32nd days after birth. Whole-cell patch clamp logs were used for electrophysiological evaluations and a decrease was observed in the neural stimulability of Purkinje cells in the offspring of rats exposed to RF radiation. However, no

behavioral anomalies were determined. Thus, it was put forth that exposure to prenatal RF radiation may change the electrophysiological properties of the Purkinje neurons, but these changes are not sufficient to affect cerebellum-related functional issues.[27]

Aldad et al. (2012) carried out behavioral and electrophysiological studies on the offspring of pregnant rats exposed to 800–1900 MHz RF radiation from cell phones with an SAR value of 1.6 W/kg. Radiation was given to different experiment groups for 0, 9, 15 and 24 hours per day throughout their pregnancy period and the offspring were subjected to behavior tests during the postnatal period. Decreased memory, decreased anxiety, and hyperactivity were observed in the offspring of all rats subject to RF radiation during the prenatal period. In addition, it was determined as a result of the electrophysiological examination that there was a glutamatergic synaptic transmission disorder in the pyramidal cells of the prefrontal cortex related with these behavioral changes. In addition, the tendency that emerged in the experiment groups subjected to RF radiation for different periods of time indicated that the effects that emerge are directly related with cell phone use time. Therefore, RF radiation exposure during pregnancy may cause neurobehavioral disorders in rats depending on irradiation. It has been expressed that exposure to electromagnetic field from cell phones during the prenatal period in recent years may have contributed to the increase in neurobehavioral disorders and hyperactivity increase in children, especially in developed countries. In conclusion, the determination of the safety limits for exposure to RF radiation, especially for pregnant women, has been emphasized.[29]

Takahashi et al. (2010) designed a comprehensive experimental study to examine the long term effects of exposure to 2.14 GHz (Downlink) W-CDMA RF signals on pregnant rats. RF signals were applied to the rats for 20 hours per day, starting from the seventh day of pregnancy until the weaning of the F1 offspring. The applied RF radiation SAR values (rats in free circulation and as full body exposure) were 0.066–0.093 W/kg for mother animals in the high level group and 0.068–0.146 W/kg for fetuses and F1 offspring, whereas the SAR levels in the low level groups were determined at approximately 43% of these values Afterwards, randomly selected male and female rats were mated when the F1 offspring was 10 weeks old and F2 fetuses were removed from F1 mothers on the 20th day of the pregnancy to evaluate the reproductive and embryotoxic parameters. In addition, evaluations were carried out throughout the experiment for mother animals related with pregnancy status and organ weights, whereas survival rates, memory functions, reproductive abilities, physical and functional development, and hormonal state evaluations were carried out for F1 offspring. Thus, no abnormal findings were observed in either the mother animals or the F1 offspring subject to RF radiation. No embryotoxic situation was stated as being related to the F2 offspring; the researchers put forth that being subjected to 2.14 GHz W-CDMA (Downlink) signals for 20 hours per day during the pregnancy and lactation period under the experimental conditions had no adverse effects on the pregnancy status or development in rats.[30]

Seckin et al. (2014) carried out an experimental study to determine the effects of the 900 and 1800 MHz RF signals emitted from cell phones on cochlear development in rats, during which they applied 900 and 1800 MHz RF signals for a period of one hour each day starting from the 12th day of pregnancy until birth on pregnant rats and for 21 days after birth on the newborn offspring. The power of the signal generator was fixed at 2 W for 900 MHz and as 1 W for 1800 MHz. (The electrical field value to which the pregnant rats were subjected was in the range 9–25 V/m for 900 MHz and 9–18 V/m for 1800 MHz, whereas it varied between 19–25 V/m and 10–18 V/m respectively for newborn rats). Distortion product otoacoustic emission (DPOAE) testing was carried out on newborn rats on the 22nd day after birth. In addition; normal, apoptotic, and necrotic cell counts at the central segment of the cochlear channel taken from the inner ear of eight newborn rats randomly selected from each group were carried out via electron microscope. Findings related with DPOAE test indicated that there was no functional hearing loss in any group. However, significant cellular damage was observed in the electronmicroscopic evaluation of the Organ of Corti in both groups that had been subjected to different electromagnetic radiation. Therefore, cochlear cellular damage was determined in newborn rats subject to RF radiation, even though there was normal functional hearing; it

was put forth that this was due to the thermal effect generated by RF energy on tissues with high fluid content.[31]

Budak et al. (2009), applied GSM 1800 MHz RF radiation to pregnant (during the 15th–22th days of pregnancy) and non-pregnant rats for a period of 15 minutes for seven days and examined the cochlear functions of rats via DPOE. They determined that there was a decrease in the DPOE amplitude of non-pregnant rats following exposure to RF radiation and claimed that this was due to the decrease in cochlear activity and decreased activity in the electromotility of the hair cells on the outside as a result of long-term exposure to radiation. They put forth that endolymph generation, which increased due to the estrogen level and the higher corticosteroid level during the pregnancy, was able to protect the inner ear from the damaging effects of RF radiation.[32] However, Yorgancilar et al. (2012) stated that long term exposure to 900 MHz RF radiation (three hour per day over six months) does not affect the cochlear function of rats.[33]

Bornhausen and Scheingraber (2000) examined the effects of the electromagnetic fields emitted from cell phones on the brain development of fetuses in Wistar rats during the pregnancy period. In that study, pregnant rats were subjected to low level (0.1 Mw/cm^2) electromagnetic radiation (SAR 17.5–75 mW/kg) at the frequency 900 MHz and pulse modulation 217 Hz (0.577 ms pulse amplitude) in accordance with GSM digital cell phone technology throughout the prenatal period. Newborn offspring were controlled via computer in test rooms (Skinner boxes) throughout the night to determine their learning deficiencies when they reached three months old. The performance scores of rats and the acquired data were evaluated, as a result of which no cognitive defect was observed due to exposure to GSM electromagnetic field during the prenatal period.[34]

Ferreira et al. (2006) measured the antioxidant enzyme activity and determined the total sulfhydryl content, protein carbonyl groups, thiobarbituric acid-reactive products and total non-enzymatic antioxidant defense action to examine the effects of RFR exposure emitted from analogue cell phones (600 mW; 834 MHz; 26.8–40 V/m; SAR 0.55–1.23 W/kg; 8.5 hours per day during pragnancy) and base stations. In addition, they examined the chromosome damage in the peripheric blood erythrocytes of newborn rats via micronucleus (MN) assay. No statistically significant difference was observed between the groups with regard to the oxidative parameters in the blood and liver, and no statistically significant change occurred in the number of offspring per birth. However, there was a statistically significant increase in MN (micronucleus) formation in newborn rats subjected to RF radiation during the prenatal period. Indicated that the RFR exposure caused an effect in the hematopoietic tissue via an unknown mechanism during embryogenesis that resulted in a genotoxic response in the tissue.[35]

Lee et al. (2009) examined the teratogenic effects on pregnant rats that were simultaneously subjected to two different types of RFR as single code division multiple access (CDMA) and wideband code division multiple access (WCDMA). WCDMA (1.95 GHz) is known as 3G and has been assigned as the universal mobile telecommunication system in the EU, Japan, and Korea. CDMA (849 MHz) is a mobile communication technology and is used in classic cell phones in Korea. CDMA (2W/Kg) and WCDMA (2 W/kg) were whole body applied to pregnant rats for two 45 minute periods with 15 minute intervals. Afterwards, the fetuses were examined with regard to mortality, growth retardation, and morphological anomalies such as changes in the size of the head. It was put forth in the light of the acquired data that being subject to CDMA and WCDMA RF signals simultaneously on the full body had no external, visceral, or skeletal effect on the fetuses of rats, indicating that RF waves with the aforementioned properties had no teratogenic effect.[36]

Pyrpasopoulou et al. (2004), examined the effects at the molecular level that might be caused in the kidneys of fetuses by pulsed GSM RFR (9.4 GHz; 0.5 mW/kg; 5 μW/cm^2; pulse repetition rate 50 Hz; pulse amplitude 20 μs). Pregnant rats were subjected to RFR separately during the first to third days of pregnancy (embryogenesis, pre-implantation) and fourth to seventh (early organogenesis, pre-implantation). Relative expression and the localizations of BMP and receptors (BMPR) that are thought of as major endocrine and autocrine mitogen protein families and that are known to be important for kidney development were examined in the kidney tissues of newborn rats experiencing radiation in two different periods as well as those in the

control group. The abnormal expressions of BMP-4 and its receptors (BMPR-IA and BMPR-II) were observed in the kidneys of the newborn offspring of mother rats subject to GSM RF radiation during early pregnancy. In light of the acquired data, it was put forth that the permanent or delayed effects of GSM RF radiation were due to exposure throughout the embryogenesis period rather than solely during the early period. Hence, the timing of RF radiation exposure on developing organisms plays an important role with regard to the development effects.[37]

Sambucci et al. (2010) carried out an experimental study to examine the effects of exposure to Wi-Fi signals during the prenatal period on the immune system components of rats. Immunological analyses were carried out on the newborn offspring of rats subjected to Wi-Fi signals during pregnancy (starting five days after mating and continuing for 14 days consecutively, two hours per day) when they were five or 26 weeks old. In addition, the gestation results of the groups were evaluated comparatively. It was determined that the SAR value for the full body exposure of the RF signals used (2.45 GHz) was 4 W/kg. No effect was observed for Wi-Fi RF radiation on mating success, number of newborn/mothers, or birth weights throughout pregnancy. Although no statistically significant difference was determined in the cell count in the spleen, the B-cell frequency or antibody level in the blood serum during the prenatal period in either young (five weeks old) or adult (26 weeks old) rats related with Wi-Fi exposure.[38]

Laudisi et al. (2012) examined the effects of the electromagnetic field emitted by Wi-Fi signals (2.45 GHz) on T cell development and function in rat fetuses. Pregnant rats were subjected to RF radiation (SAR 4 W/kg) for two hours each day throughout pregnancy starting five days after mating. Immunological examinations were carried out on newborn rats when they were five weeks and 26 weeks old. No statistically significant difference was observed in the phenotype, proliferation, or cell count of the thymocytes, cell count in the spleen, CD4/CD8 cell frequency, T cell proliferation, and cytokine generation based on RF radiation according to the obtained data.[39]

Topal et al. (2015) examined the effects of applying a 900 MHz electromagnetic field during the prenatal period on liver during the postnatal period. Sprague Dawley rats were subject to RF radiation for one hour during the 13^{th}–21^{st} days of pregnancy. Pathological changes due to oxidative stress were examined in newborn rats on the 21^{st} day after birth. The SAR value of the electromagnetic field (electrical field value 14.22 V/m, energy intensity 0.54 W/m^2) for full body exposure was calculated as 0.027 W/kg. It was determined to be as a result of the biochemical analyses carried out that there was an increase in the malondialdehyde and superoxide dismutase values in the group that had been subjected to prenatal RF radiation in addition to a decrease in the glutathione levels. Marked hydropic degeneration was determined, particularly in the central parenchyma in the sections of rats in the experiment group dyed with hematoxylin and eosin as a result of examinations carried out via light microscope. Vacuolation and enlargement in the endoplasmic reticulum and necrotic hepatocytes were observed via transmission electron microscope. Thus, it was put forth that applying a 900 MHz electromagnetic field during the prenatal period causes oxidative stress and pathological changes in the liver tissue in the postnatal period.[40]

Nakamura et al. (2003) carried out an experimental study to comparatively examine the non-thermal effects of exposure to a continuous wave of 915 Hz microwave radiation emitted from cell phones on pregnant rats with the effects due to temperature. For this, they applied microwave radiation at 915 MHz with 0.6 and 3 mW/cm^2 intensity for a period of 90 minutes on two different groups, and pregnant rats in three different groups were immersed in waters at temperatures of 34°C, 38°C and 40°C. (immersion in water at a temperature of 38°C and 40°C and microwave radiation of intensity 0.6 mW/cm^2 and 3 mW/cm^2 will result in an increase in the colonic temperature of pregnant rats of 1.0°C and 3.5°C respectively, whereas immersion in water at 34°C will result in a thermoneutral effect). The SAR values were calculated for RF radiation at 0.6 mW/cm^2 and 3 mW/cm^2 intensity were 0.4 and 2.0 W/kg respectively. Statistically significant differences were determined when the placental endocrine and immune functions in addition to the uteroplacental circulations of pregnant rats immersed in water at 34°C and 38°C were compared. No difference was observed between the rats immersed in water at 38°C and rats

subjected to 0.6 mW/cm^2 RF radiation. However, it was observed when compared with those immersed in water at 40°C that there was a statistically significant increase in the uteroplacental blood flow and estradiol levels of rats subjected to radiation at 3 mW/cm^2 intensity. In conclusion, exposure to microwave radiation at the maximum safety value allowed by American National Standards Institute (ANSI) (0.6 mW/cm^2, 915 MHz, SAR 0.4 W/kg) did not result in non-thermal effects on uteroplacental circulation, splenic natural killer cell activity (NKCA) or estradiol and progesterone levels in blood.[41]

Ogawa et al. (2009) designed a study to examine the effects of exposure to RF waves from cell phones. especially close to the head, on the embryo development of rats during which a 1.95 GHz wideband code division multiple access (W-CDMA) RF signal was applied for one 90 minute period per day on the heads of pregnant rats during the 7–17 days of the prenatal period. The average SAR values for the brain of rats in the group with low level exposure was determined as 0.67 W/kg, and as 2 W/kg for the high level group. No statistically significant difference was observed between the increase in the weights of rats during pregnancy and no external, skeletal, or visceral anomalies were indicated for any reproduction or embryotoxic parameter (live, dead, or absorbed embryo count, placenta weights, gender ratios, birth weights). No external, skeletal, or visceral anomalies were specified in any reproduction or embryotoxic parameters (in the number of live, dead, or absorbed embryos, placenta weights, gender rates, or birth weights) depending on the electromagnetic field applied.[42]

Fragopoulou et al. (2010), carried out an animal experiment to determine the effects of low exposure to the RF radiation emitted from cell phones that are used commercially by the majority of people and particularly to determine its effects on skeletal development. Physically comparable pregnant rats were subjected to GSM 900 MHz RF radiation emitted from cell phones for periods of six minutes per day and 30 minutes per day during the study. The calculated SAR value was 0.6–0.94 W/kg. No statistically significant difference was determined between the groups as a result of the external examination of newborn rats. It was determined as a result of histological and histochemical analyses that there were changes at the ossification level in the cranial bone and thoracic cage ribs in the experiment groups compared with the control group, in addition to the displacement of Meckelian cartilage. It was put forth that bone formation in the rats was affected by exposure to RF radiation emitted by cell phones for a period of only six minutes per day during the prenatal period, especially when embryonic development took place. However, it was determined that the damage to the bone development in the fetuses was temporary and that they recovered during the postnatal period.[43]

Shahin et al. (2013) planned a comprehensive study to examine the effects of 2.45 GHz (continuous wave, SAR: 0.023 W/kg) microwave radiation applied prior to the mating period of the rats and throughout the pregnancy period. The radiation application process that was started prior to the pregnancy period (two hours/day for 45 days) was continued until the 20th day of pregnancy. The rats were killed at the end of the pregnancy, after which the distribution of the placement regions for the embryos in the uterus was determined. The liver, kidneys, and eggs of the rats were removed to examine the oxidative stress parameters and blood analyses were carried out. DNA damage was examined in the brain via comet assay. When the rats that were subjected to microwave radiation were compared to the control group, the placement regions of the embryos in the uterus displayed a significant anomaly. A statistically significant increase in the number of ROS, hemoglobin, red blood cells, and white blood cells in the blood of animals subjected to radiation application in addition to neutrophil/lymphocyte ratio and a statistically significant decrease in the antioxidant enzyme activity and NO level were determined. Decreases were observed in the DNA damage in the brain and decreases in the antioxidant enzyme activity in the liver, kidneys, and eggs of rats that had been subjected to microwave radiation. In conclusion, it was put forth that microwave radiation increases ROS production in rats, thereby triggering oxidative stress and causing DNA breaks in the brain and failure in embryo placement or pregnancy anomalies.[44]

Another study examined the effects of 900, 1800 MHz (cell phone), and 2450 MHz (Wi-Fi) RF radiation on the oxidative stress levels in pregnant rats and the uteruses of their offspring in addition to the hormone levels in the plasma. The rats in the experiment groups were

subjected to RF radiation throughout the pregnancy period, whereas the offspring rats were subjected to RF radiation during their development. While the uterus lipid peroxidations of newborn rats subjected to radiation increased, the glutation peroxidase activities and plasma prolactin levels decreased. Furthermore, while the plasma prolactin, estrogen, and progesterone levels decreased in mother rats subjected to RF radiation, the plasma total oxidant levels and body temperatures increased. However, no statistically significant change occurred in the glutation and total antioxidant levels of the uterus and plasma samples of mother rats. Therefore, it was put forth that cell phone and Wi-Fi exposure causes a decrease in hormone levels in mother rats in addition to oxidative damage in the uterus of developing rats.[45]

Discussion

Wireless communication technologies (cell phone, Internet, etc.) emit RFs at 900, 1800, 2100, 2450 MHz frequency modulations in different ways. The use of these devices has increased around the world with recent developments in technology. The International Telecommunication Union has indicated that the number of internet users will reach approximately three billion and that the number of cell phone users will reach about seven billion by the end of 2014.[46] As can be clearly seen from the report by ITU, we should pay significant attention to this ever-increasing problem that is also known as electromagnetic pollution, because of its probable adverse health effects (cancer, neurological effects, developmental insufficiency effects, etc.) which result from long-term low-intensity exposure.[46] In this review, studies that examine the effects of RFs emitted from wireless communication devices on pregnant people and fetus health and development have been considered. It has been put forth by many animal studies that RF exposure below a pre-determined safety limit has adverse effects on health. However, the number of human studies related to pregnancy and the embryogenesis period is quite limited.

There are differences between various parameters such as the experimental setups, used live material, the area on which the radiation exposure is focused, the RF radiation properties (SAR, frequency, modulation type, etc.), near or far area exposure, etc. Belyaev (2010) put forth that dependency on carrier frequency value and modulation type in addition to radiation exposure duration and intervals, static magnetic field, random electromagnetic fields, genotype of the living being subjected to irradiation, gender, physiological and personal properties, cell density, etc. on the formation of non-thermal effects. Indeed, it has been indicated that exposure time is as important as power intensity and the specific absorption rate (SAR). Hence, it can be thought that the reasons for the conflicts between the results obtained from studies may be due to the aforementioned parameters.[47]

Even though Dasdag et al. determined low birth weight in the offspring of pregnant rats subject to 900 MHz RF radiation irradiation,[6] Ait-Aissa et al. (2012) carried out a study in which a low birth weight was not observed in the offspring of rats when the mothers were subjected to 2450 MHz RF radiation throughout their pregnancy.[13] Ogawa et al. (2009) applied a 1.95 GHz wideband code division multiple access (W-CDMA) signal to the heads of pregnant rats for a period of 90 minutes during the 7–17 days of the prenatal period.[42] No difference was determined between the weight increases in the rats between the groups throughout pregnancy. No external, skeletal, or visceral abnormalities were indicated in live fetuses, neither were any reproductive or embryotoxic parameters (number of living, dead, absorbed embryo, placenta weights, gender ratios, or birth weights) different due to the applied electromagnetic field. No teratogenic effect was observed on rats subjected to 2450 MHz RF radiation during the prenatal period.[11] Lee et al. (2009) determined that no external, visceral, or skeletal defects occurred in the fetuses of rats subjected to simultaneous full body exposure CDMA and WCDMA RF signals, meaning that no teratogenic effect was produced.[36] Fragopoulou et al. (2010) reported that being subject to RF radiation emitted by cell phones for a period of only six minutes per day during the prenatal period when embryonic development takes place had adverse effects on the rats' bone formation.[43] However, it has been determined that the defects that occurred in the bone development of the fetuses were temporary and that they were ameliorated during the postnatal period. Takahashi et al. (2010) expressed that, based on data acquired from

experimental studies carried out, being exposed to 2.14 GHz W-CDMA (Downlink) signals for long periods of time had no adverse effects on the pregnancy state or development of rats.[30]

It has been pointed out in studies that 1800 MHz RF radiation might cause changes in the oxidative stress parameters in the brain and liver tissues of pregnant rabbits and their offspring and DNA damage.[7-9] Topal et al. (2015) determined that a 900 MHz electromagnetic field applied during the prenatal period causes oxidative stress and pathological changes in the liver tissue during the postnatal period.[40] Shahin et al. (2013) reported that 2.45 GHz (continuous wave, SAR: 0.023 W/kg) microwave radiation caused DNA damage in the brain and decreases in the antioxidant enzyme activity in the liver, kidneys, and ovaries when applied during the mating period and throughout pregnancy.[44] Whereas, Ferreira et al. (2006) applied 834 MHz RF radiation on pregnant rats for 8.5 hours per day starting from the first day of the pregnancy, and has not observed a statistically significant difference between the blood and liver oxidative stress parameters of offspring rats in different groups; however, MN formation had increased by a statistically significant level in newborn rats subjected to RF radiation during the prenatal period. In this case, results have indicated that a high frequency electromagnetic field produces an effect that will result in a genotoxic response in the hematopoietic tissue during the embryogenesis period via an unknown mechanism.[35] Yuksel et al. (2016) carried out an experimental study in which it was put forth that cell phone and Wi-Fi exposure may result in decreased hormone levels in mother rats in addition to oxidative stress in the uterus of developing rats.[45]

De Gannes et al. (2009) carried out an experimental study in which it was observed that there was no change in the antibody level for the 16 antigens that are known indicators for neurodegenerative and autoimmune processes in rats subjected to 2450 MHz RF radiation during the pregnancy period.[10] Ait-Aissa et al. (2012) carried out a study during which pregnant rats were subjected to 2450 MHz RF radiation for five days per week, two hours per day during the 6–21 days of the pregnancy. Even though a wide range of antigens were tested, no change was determined in the immunoglobulin levels of the young rats subjected to Wi-Fi.[13] Sambucci et al. (2010) carried out immunological studies, the results of which found no statistically significant difference in the cell count in the spleen, B-cell density or antibody level in the blood depending on 2450 MHz Wi-Fi exposure in either young (5 weeks old) or adult (26 weeks old) rats as a result of immunological studies.[38] Laudisi et al. (2012) examined the effects of the electromagnetic field emitted by Wi-Fi signals (2.45 GHz) on the T cell development and function in rat fetuses as a result of which they observed no difference in the phenotype, proliferation, and cell count of thymocytes, number of cells in the spleen, CD4/CD8 cell frequency, proliferation of T cells, and cytokine generation depending on the RF radiation.[39]

It was indicated that exposure to 2450, 900, and 1800 MHz RF radiation during the prenatal and postnatal periods may result in early adolescence and oxidative damage in the kidneys in rat offspring.[18] Pyrpasopoulou et al. (2004) examined the effects that might occur in the kidneys of the fetus at the molecular level when pulsed GSM RF (9.4 GHz) radiation was applied to Wistar rats during the early pregnancy period. Abnormal expression was observed in the BMP-4 and its receptors (BMPR-IA and BMPR-II) in the kidneys of the newborn offspring of mother rats subjected to GSM RF radiation during the early pregnancy period.[37]

Ait-Aissa et al. (2010) examined the effects on the central nervous system of young rats subjected to Wi-Fi signals (2.45 GHz, SAR: 0, 0.08, 0.4, 4 W/kg) during the prenatal (two hours/day, five days/week, for a period of two weeks between the 6th day of pregnancy to the 21st day) and the first weeks of the postnatal period (the first five weeks until the weaning period). Changes were determined in the astrocytic and apoptotic structures, particularly indicating postnatal brain development in different selected regions of the brain. However, the results obtained put forth that the Wi-Fi signals used did not result in permanent astroglia activation in the brains of young rats under the experimental conditions and that they did not trigger apoptosis.[12] Odaci et al. (2008) reported that the number of dentate gyrus granule cells in the hippocampus decreased in the offspring of rats which were subject to 900 MHz RF for a period of 60 minutes per day throughout the pregnancy period (Odaci et al., 2008). Statistically significant decrease in the number of

pyramidal cells in the hippocampus of the offspring of rats subject to 900 MHz radiation during the prenatal period for 60 minutes per day[23] as well as the existence of pyknotic cells in the Cornu Ammonis region of the hippocampus on the 32nd day of the postnatal period.[26] Whereas, Ragbetli et al. (2009) indicated no difference in the number of pyramidal cells in the Cornu Ammonis region of the hippocampus in the offspring of pregnant rats subjected to 890–915 MHz RF radiation for a period of 15 minutes per day throughout the pregnancy period,[24] a tendency for increase in the number of granule cells in the cerebellum and a statistically significant decrease in the Purkinje cells were determined.[25] It was put forth in another study that exposure to 900 MHz pulsed RF radiation during pregnancy may change the electrophysiological properties of the Purkinje neurons of the offspring rats during the postnatal period, but that these changes are not sufficient to affect cerebellum-related functional operations.[27] Finnie et al. (2009) carried out an experimental study during which there was no observed change in comparison with the control group for the expression of the c-fos gene, which is an indication of neural stress in the brains of the offspring subjected to RF radiation during the prenatal period.[28]

Aldad et al. (2012) determined that exposure to 800–900 MHz RF radiation during the prenatal period can cause neurobehavioral disorders in the offspring of pregnant rats, depending on the exposure time.[29] It has been expressed that exposure to 900 MHz GSM electromagnetic fields during the prenatal period causes no cognitive deficit.[34]

Various researchers have examined the effects of RF radiation on cochlear development thinking that it may be significantly affected by RF radiation due to its high fluid content. Seckin et al. (2014) applied 900 and 1800 MHz RF radiation to pregnant rats, as a result of which they determined that there was cochlear cellular damage in the offspring rats despite their normal functional hearing.[31] Budak et al. (2009) reported that GSM 1800 MHz RF radiation caused a decrease in cochlear activity.[32]

Conclusions

In conclusion, the majority of the studies, almost all of which were based on animal studies, put forth that pregnancies and therefore babies may be adversely affected by RFRs. However, the fact that there are studies that indicate just the opposite make this a matter of debate. This causes losses in both time and economic losses. Despite all these, the results of the studies summarized above indicate that RF exposure during pregnancy is not that benign and rules for the use of wireless communication tools should therefore be taken into consideration. These rules, which are very important for the health of mothers, babies, and society, should limit any concerns related to wireless communication devices that are widely used. Human studies at the molecular level are needed soon to clearly determine whether RFRs have an effect on pregnant women and therefore on fetuses.

Declaration of Interest

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References

1. Bioinitiative Working Group. Fetal and Neonatal Effects of EMF. 2012;19:8-9.
2. Keshvari J, Keshvari R, Lang S. The effect of increase in dielectric values on specific absorption rate (SAR) in eye and head tissues following 900, 1800 and 2450 MHz radio frequency (RF) exposure. Physics in Medicine and Biology. 2006; 51(6):1463-77.
3. Heynick LN, Merritt JH. Radiofrequency fields and teratogenesis. Bioelectromagnetics. 2003;24:174-186.
4. Panagopoulos DJ, Chavdoula ED, Nezis IP, Margaritis LH. Cell death induced by GSM 900 MHz and DCS 1800 MHz mobile telephony radiation. Mutation Research. 2007;626:69-78.
5. Kheifets L, Repacholi M, Saunders R, Van Deventer E. The sensitivity of children to electromagnetic fields. Pediatrics. 2005;116(2):303-313.
6. Dasdag S, Akdag MZ, Ayyildiz O, et al. Do cellular phones alter blood parameters and birth weight of rats. Electro and Magnetobiolog. 2000;19(1):107-113.
7. Guler G, Tomruk A, Ozgur E, Seyhan, S. The effect of radiofrequency radiation on DNA and lipid damage in non-pregnant and pregnant rabbits and their newborns. General Physiol and Biophysics. 2010;29:59-66.
8. Tomruk A, Guler G, Dincel AS. The influence of 1800 MHz GSM-like signals on hepatic oxidative dna and lipid damage in nonpregnant, pregnant, and newly born rabbits. Cell Biochem Biophys. 2009;56(1):39-47.
9. Guler G, Tomruk A, Ozgur E, et al. The effect of radiofrequency radiation on DNA and lipid damage in female and male infant rabbits. International Journal of Radiation Biology. 2012;88(4):367-373.
10. De Gannes PF, Taxile M, Duleu S, et al. A confirmation study of Russian and Ukrainian data on effects of 2450 MHz microwave exposure on immunological processes and teratology in rats. Radiation Research. 2009;172:617-624.
11. De Gannes PF, Haro E, Hurtier A, et al. Effect of in utero Wi-Fi exposure on the pre and postnatal development of rats. Birth Defects Res B Dev Reprod Toxicol. 2012;95(2):130-136.

12. Ait-Aissa S, Billaudel B, De Gannes FP, et al. In situ detection of gliosis and apoptosis in the brains of young rats exposed in utero to a Wi-Fi signal. C. R. Physique. 2010;11:592-601.
13. Ait-Aissa S, Billaudel B, De Gannes FP, et al. In utero and early-life exposure of rats to a Wi-Fi signal: Screening of immune markers in sera and gestational outcome. Bioelectromagnetics. 2012;33:410-420.
14. Wathes DC, Abayasekara DR, Aitken RJ. Polyunsaturated fatty acids in male and female reproduction. Biol Reprod. 2007;77:190-201.
15. Atasoy HI, Gunal MY, Atasoy P, et al. Immunohistopathologic demonstration of deleterious effects on growing rat testes of radiofrequency waves emitted from conventional Wi-Fi devices. J Pediatr Urol. 2013;9:223-229.
16. Jelodar G, Nazifi S, Akbari A. The prophylactic effect of vitamin C on induced oxidative stress in rat testis following exposure to 900 MHz radio frequency wave generated by a BTS antenna model. Electromagn Biol Med. 2013;32:409-416.
17. Dasdag S, Tas M, Akdag MZ, Yegin K. Effect of long-term exposure of 2.4 GHz radiofrequency radiation emitted from Wi-Fi equipment on testes functions. Electromagnetic Biology and Medicine. 2015;34(1):37-42.
18. Ozorak A, Nazıroglu M, Celik O, et al. Wi-Fi (2.45 GHz) and mobile phone (900 and 1800 MHz) ınduced risks on oxidative stress and elements in kidney and testis of rats during pregnancy and the development of offspring. Biol Trace Elem Res. 2013;156(1-3):221-229.
19. Salford LG, Brun AE, Eberhardt JL, et al. Nerve cell damage in mammalian brain after exposure to microwaves from GSM mobile phones. Environ Health Perspect. 2003;111:881-883.
20. Rodier PM. Chronology of neuron development: Animal studies and their clinical implications. Dev Med Child Neurol. 1980;22:525-545.
21. Lemaire V, Koehl M, Le Moal M, Abrous DN. Prenatal stress produces learning deficits associated with an inhibition of neurogenesis in the hippocampus. Proc Natl Acad Sci USA. 2000;97:11032-11037.
22. Odaci E, Bas O, Kaplan S. Effects of prenatal exposure to a 900 MHz electromagnetic field on the dentate gyrus of rats: A stereological and histopathological study. Brain Research. 2008;1238:224-229.
23. Bas O, Odaci E, Mollaoglu H, et al. Chronic prenatal exposure to the 900 megahertz electromagnetic field induces pyramidal cell loss in the hippocampus of newborn rats. Toxicology and Industrial Health. 2009;25:377-384.
24. Ragbetli MC, Aydinlioglu A, Koyun N, et al. Effect of prenatal exposure to mobile phone on pyramidal cell numbers in the mouse hippocampus: A stereological study. International Journal of Neuroscience. 2009;119(7):1031-1041.
25. Ragbetli MC, Aydinlioglu A, Koyun N, et al. The effect of mobile phone on the number of Purkinje cells: A stereological study. International Journal of Radiation Biology. 2010;86(7):548-554.
26. Bas O, Sönmez OF, Aslan A, et al. Pyramidal cell loss in the cornu ammonis of 32-day-old female rats following exposure to a 900 megahertz electromagnetic field during prenatal days 13–21. NeuroQuantology. 2013;4:591-599.
27. Haghani M, Shabani M, Moazzami K. Maternal mobile phone exposure adversely affects the electrophysiological properties of purkinje neurons ın rat offspring. Neuroscience. 2013;250:588-598.
28. Finnie JW, Cai Z, Blumbergs PC, et al. Expression of the immediate early gene, c-fos, in fetal brain after whole of gestation exposure of pregnant mice to global system for mobile communication microwaves. Experimental Pathology. 2009;38(4):333-335.
29. Aldad TS, Gan G, Gao XB, Taylor HS. Fetal radiofrequency radiation exposure from 800-1900 Mhz-rated cellular telephones affects neurodevelopment and behavior in mice. Scientific Reports. 2012;2:312.
30. Takahashi S, Imai N, Nabae K, et al. Lack of adverse effects of whole-body exposure to a mobile telecommunication electromagnetic field on the rat fetus. Radiation Research. 2010;173(3):362-372.
31. Seckin E, Basar FS, Atmaca S, et al. The effect of radiofrequency radiation generated by a Global System for Mobile Communications source on cochlear development in a rat model. J Laryngol Otol. 2014;128(5):400-405.
32. Budak GG, Muluk NB, Öztürk GG, et al. Effects of GSM-like radiofrequency on distortion product otoacoustic emissions in pregnant adult rabbits. Clin Invest Med. 2009;32(2):112-116.
33. Yorgancilar E, Dasdag S, Akdag MZ, et al. Long-term effect of 900 Mhz radiofrequency radiation exposure on cochlear functions. Biotechnology & Biotechnological Equipment. 2012;26(6):3397-3401.
34. Bornhausen M, Scheingraber H. Prenatal exposure to 900MHz, cell-phone electromagnetic fields had no effect on operant-behavior performances of adult rats. Bioelectromagnetics. 2000;21:566-574.
35. Ferreira AR, Knakievicz T, Pasquali MA, et al. Ultra high frequency-electromagnetic field irradiation during pregnancy leads to an increase in erythrocytes micronuclei incidence in rat offspring. Life Sciences. 2006;80(1):43-50.
36. Lee HJ, Lee JS, Pack JK, et al. Lack of teratogenicity after combined exposure of pregnant mice to CDMA and WCDMA radiofrequency electromagnetic fields. Radiation Research. 2009;172(5):648-652.
37. Pyrpasopoulou A, Kotoula V, Cheva A, et al. Bone morphogenetic protein expression in newborn rat kidneys after prenatal exposure to radiofrequency radiation. Bioelectromagnetics. 2004;25(3):216-227.
38. Sambucci M, Laudisi F, Nasta F, et al. Prenatal exposure to non-ionizing radiation: Effects of WiFi signals on pregnancy outcome, peripheral b-cell compartment and antibody production. Radiation Research. 2010;174(6a):732-740.
39. Laudisi F, Sambucci M, Nasta F, et al. Prenatal exposure to radiofrequencies: Effects of Wi-Fi Signals on thymocyte development and peripheral t cell compartment in an animal model. Bioelectromagnetics. 2012;33:652-661.
40. Topal Z, Hanci H, Mercantepe T, et al. 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. 2015;45:291-297.
41. Nakamura H, Matsuzaki I, Hatta K, et al. Nonthermal effects of mobile-phone frequency microwaves on uteroplacental functions in pregnant rats. Reproductive Toxicology. 2003;17:321-326.
42. Ogawa K, Nabae K, Wang J, et al. Effects of gestational exposure to 1.95-GHz W-CDMA signals for IMT-2000 cellular phones: Lack of embryotoxicity and teratogenicity in rats. Bioelectromagnetics. 2009;30(3):205-212.
43. Fragopoulou AF, Koussoulakos SL, Margaritis LH. Cranial and postcranial skeletal variations induced in mouse embryos by mobile phone radiation. Pathophysiology. 2010;17:169-177.
44. Shahin S, Singh VP, Shukla RK, et al. 2.45 GHz microwave ırradiation-ınduced oxidative stress affects ımplantation or pregnancy in mice. Appl Biochem Biotechnol. 2013;169:1727-1751.
45. Yuksel M, Naziroglu M, Ozkaya 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. 2016;52(2):352-362.
46. Dasdag S, Akdag MZ. The link between radiofrequencies emitted from wireless technologies and oxidative stress. Journal of Chemical Neuroanatomy. 2016;75:85-93.
47. Belyaev IY. Dependence of non-thermal biological effects of microwaves on physical and biological variables: Implications for reproducibility and safety standards. (In ICEMS Monograph Edited by Giuliani, L., Soffritti, M.; Non-Thermal Effects and Mechanisms of Interaction Between Electromagnetic Fields and Living Matter). Eur J Oncol. 2010;5:87-210.