Oxidative Effects of Electromagnetic Radiation on Liver, Lung, Kidney and Heart Tissues of Diabetic and Normal Rats

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ABSTRACT

Purpose: The possible health risks of Radiofrequency Radiation (RFR) and Extremely Low-Frequency Magnetic Fields (ELF-MF) are becoming popular subjects for scientific interest. The objective of this study was to observe the possible effects of 50 Hz ELF-MF and 2100 MHz RFR on diabetic and normal rat liver, lung, kidney and heart tissues using oxidant parameters after one-month exposure.

Material and Methods: 60 adult wistar albino rats were used for the present study. 2100 MHz RFR exposure (SAR: 0.23 W/kg) was performed for one month (30 min/day, 5 days/week). ELF-MF (50 Hz) were used with 8 Gauss for 30 min/day, 5 days per week for one month. There were 10 groups (n=6): Control (C), Control Diabetic (C-D), Sham (S), Sham Diabetic (S-D), ELF magnetic field exposed (ELF) and ELF magnetic field exposed Diabetic (ELF-D), RFR exposed (RFR), RFR exposed Diabetic (RFR-D), ELF-MF and RFR exposed (ELF-RFR) and ELF-MF-RFR exposed Diabetic (ELF-RFR-D).

Results: ELF and RFR exposures increased the NO and MDA levels (p < 0.05), and decreased the GSH levels (p < 0.05), yet more significantly in diabetic rats. The most marked effect was observed in ELF-RFR-D group (p < 0.05).

Conclusion: Both radiation exposures caused oxidative stress in tissues while decreasing the antioxidant level more distinctively in diabetic rats.

Keywords: Oxidative Stress; Extremely Low Frequency Magnetic Fields (ELF-MF); Radio-Frequency Radiation (RFR)

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ÖZET

Amaç: Radyofrekans Radaysonunun (RFR) ve Çok Düşük Frekanslı Manyetik Alanların (ÇDF-MF) olması sağlık riskleri, son yıllarda popüler araştırma konusu haline gelmektedir. Bu çalışmanın amacı, diyabetik ve normal sıçanlarda bir ay boyunca 50 Hz ELF-MF ve 2100 MHz RFR maruziyetinin karaciğer, akciğer, böbrek ve kalp dokularda oksidatif etkilerini incelmekle ilgilidir.

Yöntem: Bir ay boyunca 2100 MHz RFR (30 dakika / gün, 5 gün / hafta, SAR: 0.23 W / kg) maruziyet uygulandı. ELF-MF maruziyeti (50 Hz), 8 Gauss ile 30 dakika / gün, haftada 5 gün, bir ay süreyle uygulandı. 10 grup (n = 6) oluşturuldu: Kontrol (C), Kontrol Diyabetik (CD), Sham (S), Sham Diyabetik (SD), ELF uygulanan Diyabetik (ELF-D), RFR uygulanan (RFR), RFR uygulanan Diyabetik (RFR-D), ELF-MF ve RFR uygulanan (ELF-RFR) ve ELF-MF-RFR’ye maruz kalan Diyabetik (ELF-RFR-D) grup olarak gruplar belirlendi. Doku glutatyon (GSH), malondialdehit (MDA) ve toplam nitrik oksit (NO) seviyelerini incelendi.

Bulgular: ELF ve RFR maruziyeti, hem diyabetik hem de diyabetik olmayan sıçanlarda NO ve MDA seviyelerini arttırdı (p < 0.05) ve GSH seviyelerini düşürdu (p < 0.05), diyabetik gruplarda bu fark daha anlamlı olarak gözlemlendi. En belirgin etki ELF-RFR-D grubunda görüldü (p < 0.05).

Sonuç: Her iki radyasyona maruz kalma, dokularda oksidatif stres neden olurken, diyabetik sıçanlarında antioksidan seviyesini daha belirgin bir şekilde düşürtür.

Anahtar Sözcükler: Oksidatif Stres; Çok Düşük Frekanslı Manyetik Alanlar (ÇDF-MF); Radyo Frekansı Radaysonu (RFR)

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INTRODUCTION

Daily exposure to extremely low-frequency magnetic fields (ELF-MF) and Radio-Frequency Radiation (RFR) might be harmful to human health. The debate about biological effects of this fields has become a public health concern in the last 30 years. This has resulted in the classification of ELF-MF and RFR into category 2B in 2002 and in 2011 respectively, i.e., agents that are “possibly carcinogenic to humans” by the International Agency for Research on Cancer (IARC) (1-2). Many studies have declared an association between ELF-MF and RFR exposures and human health, with a variety of clinical diseases, including: cancer (brain, colon, breast), neurodegenerative diseases, acute childhood leukemia, genotoxicity, increased risk of miscarriage, infertility, and others (3-7). Su et al. (8) reported that paternal exposure to ELF-MF can be risk factor for childhood leukemia and childhood leukemia. Greenland et al. (9) have published a pooled analysis study about ELF-MF and childhood leukemia. Together, these analyses from a number of well-designed studies show a fairly consistent association between ELF-MF and childhood leukemia strengths above 0.4 μT, with an approximately two-fold increase in risk. The WHO/IARC has classified RFR as possibly carcinogenic to humans (Group 2B), based on an increased risk for brain cancer, associated with wireless phone use (2).

In general population, normal and sick people expose RFR due to increasing demand of usage of household and office instruments and mobile phones and related base stations, and one of the most common disease is diabetes in modern life. Diabetes, called ‘diabetes mellitus’ in clinical terminology, is a very serious and growing health care problem worldwide and is associated with severe acute and chronic complications. Diabetes is characterized by hyperglycemia and vascular complications. The primary cause of these complications is chronic hyperglycemia. Hyperglycemia can increase production of free radicals and subsequent oxidative damage. Excessive production of the free radicals cause oxidative stress (10). It is thought that diabetes is a disease that can exacerbate the oxidative damage. So diabetes can make the person more prone to the oxidative damage (11). Streptozotocin (STZ) is an agent used to induced diabetes in animals via its toxic effects on pancreatic beta cells. STZ behaves as a potential source of oxidative stress, which induces genotoxicity (12).

Oxidative stress can effect many physiological and cellular processes such as cell growth, gene expression, and cell death. Free radicals are reactive charged particles with unpaired electrons (13). Free radicals such as reactive oxygen species (ROS) and reactive nitrogen species (RNS) have an essential role in many biochemical events when they are at low concentrations (14). However, high levels of the free radicals lead to oxidative and nitrosative stress (15). Manikonda et al (16) investigated the influence of long-term exposure of rats to ELF-MF, focusing on oxidative effects of this fields on different regions of rat’s brain. They found that ELF-MF increased oxidative stress and altered glutathione (GSH/GSSG) levels in all the regions of the brain tissue. Also oxidative stress caused by ELF-MF exposure was more significant at 100 μT than at 50 μT. Dent et al (17) studied the effect of aluminum and ELF-MF (2 mT, 4 h/day, 8 weeks) on oxidative stress and the memory of mice. Memory impairment was assessed with the Morris water maze (MWM) task. Pathologic abnormalities such as overexpression of phosphorylated tau protein and neuronal cell loss in the hippocampus and cerebral cortex was also investigated. The results showed a significant increase in the levels of malondialdehyde (MDA) and statistically decreased in superoxide dismutase (SOD) activity in the ELF-MF group, ELF-MF + Al (aluminum) group, and load Al group in brain and serum. However, ELF-MF + Al treatment caused no more hazardous than aluminum and ELF-MF did, respectively. Akdag et al (18) showed that exposure to 100 μT and 500 μT ELF-MF had no affect on lipid peroxidation, oxidative or antioxidative processes, or reproductive system such as testes morphology and sperm count of rats. However, ELF-MF exposure (500 μT) affected active-caspase-3 activity in long term exposure cases, which is a well-known apoptotic indicator. Wyzgowska et al. (19) studied the effects of 50 Hz, 7 mT MF on male Wistar rats by using two different time period, i.e.24 hour for 1 day or 1 hour for 7 days exposures. Results showed that while 24 hour for 1 day ELF-MF exposure lead to increase in inflammatory cytokines, 1 hour for 7 days exposure did not cause to any changes. In a study from Duan et al. (20), mice were exposed to ELF-MF (28 day, 4 h/day, 50 Hz, 8 mT). After exposure, cognitive functions were tested by Morris Water Maze test and hippocampus tissues were analysed for markers of oxidative stress. They observed that ELF-MF exposure caused memory and learning deficit and oxidative damage in hippocampus tissues of the mice.

Recently, many experiments has been carried out to analyze possible oxidative effects of RFR exposure. A number of studies reported several apparently pathophysiological effects of mobile phone exposure on various tissues, including reproductive organs (21-24). It has also been found that electromagnetic field exposure induced reversible or irreversible functional and structural changes at the cellular level (25-26). In recent years, many studies observed that mobile telephones could increase free radical formation in tissues because of the EMF they produce, which finally results in oxidant damage (27-28). In the current study, it was aimed to compare the effects of each exposures and wanted to see if there is an extra effect of both exposures taken at the same animals. The aim of present study was to examine whether exposure to the ELF-MF and 2.1 GHz RFR leads to oxidative damage to the liver, lung, kidney and heart tissues of diabetic and normal rats.

MATERIALS and METHODS

Experimental setup and treatments

Sixty adult male Wistar albino rats (220-270 g) were used in the experiment. The rats were randomly separated into 10 groups equally (n=6 for each group): Control (C), Control Diabetic (C-D), Sham (S), Sham Diabetic (S-D), ELF magnetic field exposed (ELF) and ELF magnetic field exposed Diabetic (ELF-D), RFR exposed (RFR), RFR exposed Diabetic (RFR-D), ELF-MF and RFR exposed (ELF-RFR) and ELF-MF and RFR exposed Diabetic (ELF-RFR-D). All rats were placed in plastic cages in a room with humidity (50 ± 5%), temperature (22 °C), and a 12-hours light dark cycle. All procedures of the study were carried out with the permission of the Guangxi University Experimental Animals Local Ethics Committee. The rats were fed laboratory pellet chow and water was given ad libitum. After several days of stabilization period of the animals the experiment was performed. The ELF group animals were exposed to 50 Hz magnetic fields and RFR group animals were exposed to 2100 MHz RFR for 30 min/day, 5 days/week for one month. No experimental manipulation was performed to control group animals. By a single intraperitoneal injection of STZ (65 mg/kg, Sigma-Aldrich, St. Louis, MO) diabetes was induced. Blood glucose was measured after 72 hours following the injection using a glucose meter (Life Scan Inc., USA). Animals with blood glucose levels over 250 mg/dl were considered as diabetic. After exposure period (one-month), the rats were decapitated following anesthesia with intramuscular ketamine (50 mg/kg) and xylazine (5 mg/kg) injection.

Exposure system

Details of the ELF-MF exposure system (Figure 1) has been described before (29). Briefly, by using circular Helmholtz coils with winding embedded in an open wooden circular frame a 50 Hz MF of 8 Gauss was generated. The system consisted of two parallel horizontal flat circular coils (21.375 cm apart and 42.75 cm in diameter with a common axis). Each coil was constructed of insulated copper wire and had 154 turns. 50 Hz sinusoidal current was created at the output of the circuit driven by a specially designed variable transformer, 2.7 kVA in power (Navelson, Ankara, Turkey) that allowed modulation of the intensity of the MF. The MF value at the center of the exposure system was measured by Electromagnetic Field Analyzer (EFA 300, Narda, Germany). The background geomagnetic field value was recorded as 20 microT. Rats were placed in plastic cage and the cage (polymethyl methacrylate, 15 x 20 x 20 cm) was placed symmetrically throughout the center axis and perpendicular to the mid-line of the coils. In order to avoid the temperature increase inside the cage, the cage was constantly aerated.
RFR exposure performed by using vector signal generator (Rohde & Schwartz, model SMBV100A, Germany) and horn antenna (ETS Lindgren, Model 3164-03, USA) (Figure 2). Rats were housed in plastic cage (polymethyl methacrylate plastic cage). The cage was placed symmetrically along the axis of the horn antenna.

Figure 1. ELF magnetic fields exposure system

Figure 2. RFR exposure system

Measurement of tissue lipid peroxidation and GSH levels

Lesion areas were measured and tissue samples were kept in -80°C until the assay. By measuring the formation of thiobarbituric acid reactive substances (TBARS) lipid peroxidation was quantified. Homogenization of the samples were done in a tissue homogenizer (Heideloph Diax 900, Germany) in ice-cold trichloroacetic acid (TCA, 1 g tissue in 10 ml 10% TCA). Homogenate was centrifuged for 10 min at 3000 × g (Hermle Z 323 K, Germany). After this step 750 μl of supernatant was added to an equal volume of 0.67% thiobarbituric acid (TBA) and heated at 100°C for 15 min. Samples absorbance was measured at 535 nm. Lipid peroxide levels are expressed in terms of MDA equivalents by using an extinction coefficient of 1.56 × 105 l·mol−1·cm−1.

By Ellman method with some modification the GSH levels were determined. Briefly, centrifugation (3 000 × g for 10 min) of the homogenates were performed. 0.5 ml of supernatant was added to 2 ml of 0.3 M Na2HPO4·2H2O solution. After this, dithiobisnitrobenzoate solution (2 ml, 0.4 mg/ml 1% sodium citrate) was added. The absorbance of the samples at 412 nm was measured with a spectrophotometer (UV 1208, Shimadsu, Japan). The GSH levels were calculated with an extinction coefficient of 13 600 l·mol−1·cm−1.

Determination of NO (Griess assay)

NO levels of the tissues were obtained from Elisa reader by vanadium chloride (VCI3)/Griess assay. Tissue homogenization was performed in phosphate buffer saline (pH = 7) and samples were centrifuged for 5 min at 2000 × g. After centrifugation step, 0.25 ml of 0.3 M NaOH was added to 0.5 ml supernatant. The samples incubated for 5 min at room temperature. 0.25 ml of 5% (w/v) ZnSO4 was added following the incubation. The mixture was then centrifuged (3000 × g for 20 min). After centrifugation supernatants were used for the assays. Serial dilution of the Nitrate standard solution was performed and the samples loaded to the plates (100 μl). Griess reagents sulphanilamide (SULF) (50 μl) and Vanadium III chloride (VCl3) (100 μl) and N-[1-naphthyl] ethylenediamine dihydrochloride (NEDD) (50 μl) were added to each well. Samples were incubated in 37°C for 45 min, and measurements were done at 540 nm using ELISA reader (34).

Statistical analysis
All data were presented as mean values ± SD. Kruskal Wallis and Mann-Whitney U test was used. p < 0.05 considered as statistically significant. Data were analyzed by using SPSS version 13.0.

Ethical Statement

To prevent the temperature increase inside the cage, the cage was constantly aerated. In order to get sufficient field intensity the cage was placed in the near field area of the antenna. RFR electric field was measured was performed with Broadband RF Survey Meter (Narda EMR 300, Germany) via the appropriate electric field probe type 8.3. Electric field value of was measured as 17.25 V/m. The background electric field level was measured as 0.1 - 0.21 V/m. Power density average value was measured at the mid-point of the bottom of the cage. The maximum value of the power density was found throughout the axis of the antenna and uniformly decreased with the distance from the antenna.

The specific absorption rate (SAR, W/kg) is a fundamental dosimetric quantity of RFR (30). The SAR value of 4 W/kg is known as the threshold for the induction of biological thermal effects of RFR (31). SAR value was calculated using the following equation: SAR = σ/ρ|E|2[W/kg], σ is the mean electrical conductivity of the tissue Siemens/meter (S/m), ρ is the mass density (kg/m3) and |E|2 is the root mean square value of the electric field (V/m) inside the tissue (32-33). Based on the average of the dielectric properties the rat body was considered as an equivalent tissue of the 36 tissues in the rat segmented at Brook Air Force Base. Mass density (1105 kg/m3) and conductivity (0.87 S/m) were derived from the equivalent tissue by using dielectric properties and mass densities of these tissues. Whole body average SAR value was calculated as 0.23 W/kg.

Prior and after exposure session body temperature (rectal) of rats was recorded. The RFR exposure did not cause any changes in rectal temperature values of the rats. Electromagnetic field applications of the ELF-MF and RFR groups were done to the animal one by one separately.
RESULTS

RFR exposure decreased GSH levels in heart, kidney, lung and liver tissues of diabetic and nondiabetic rats. ELF exposure decreased GSH levels in lung and heart tissues. When RFR and ELF exposure applied together, it was observed that GSH levels decreased in all tissues. RFR exposure increased MDA levels in all tissues. Different results were observed in different tissues. No statistically significant differences were observed between control and sham groups. Results were presented in tables (Table 1-4).

Table 1. Mean ± SD values of MDA, NO and GSH levels in liver tissues

| Group                          | MDA (nmol/g) | NO (µmol/g) | GSH (nmol/g) |
|--------------------------------|--------------|-------------|--------------|
| Control                        | 2.74 ± 0.29  | 9.51 ± 0.91 | 10.47 ± 0.88 |
| Sham                           | 2.66 ± 0.09  | 9.72 ± 0.81 | 10.90 ± 0.89 |
| RFR exposed                    | 3.51 ± 0.47* | 11.46 ± 1.72 | 9.22 ± 0.88* |
| ELF exposed                    | 3.19 ± 0.38* | 11.77 ± 1.95* | 10.21 ± 1.50 |
| RFR + ELF exposed              | 4.99 ± 0.88* | 11.44 ± 2.40 | 8.74 ± 0.83* |
| Control diabetic               | 4.86 ± 0.70  | 13.56 ± 1.80 | 8.95 ± 0.21  |
| Sham diabetic                  | 4.83 ± 0.86  | 13.27 ± 1.25 | 8.88 ± 0.28  |
| RFR exposed diabetic           | 5.86 ± 0.71* | 13.99 ± 1.24 | 8.10 ± 0.62* |
| ELF exposed diabetic           | 5.30 ± 0.33  | 14.09 ± 1.04 | 8.90 ± 0.59  |
| RFR + ELF exposed diabetic     | 5.56 ± 0.78* | 15.96 ± 1.56* | 6.40 ± 1.03* |

The values are means ± SD; n = 6. * shows statistically important results (p < 0.05) with respect to their own sham or control groups.

Table 2. Mean ± SD values of MDA, NO and GSH levels in lung tissues

| Group                          | MDA (nmol/g) | NO (µmol/g) | GSH (nmol/g) |
|--------------------------------|--------------|-------------|--------------|
| Control                        | 4.34 ± 0.63  | 9.21 ± 1.14 | 3.77 ± 0.20  |
| Sham                           | 4.38 ± 0.44  | 9.25 ± 1.15 | 3.78 ± 0.27  |
| RFR exposed                    | 4.96 ± 0.40* | 10.27 ± 1.13 | 3.50 ± 0.24  |
| ELF exposed                    | 4.68 ± 0.26  | 11.13 ± 1.72* | 3.33 ± 0.31* |
| RFR + ELF exposed              | 4.75 ± 0.49  | 12.85 ± 0.97* | 3.17 ± 0.32* |
| Control diabetic               | 5.24 ± 0.53  | 14.23 ± 1.26 | 3.17 ± 0.42  |
| Sham diabetic                  | 5.15 ± 0.66  | 13.96 ± 1.71 | 2.96 ± 0.24  |
| RFR exposed diabetic           | 6.41 ± 0.65* | 14.68 ± 1.72 | 2.45 ± 0.39* |
| ELF exposed diabetic           | 6.07 ± 0.25* | 15.10 ± 1.51 | 2.70 ± 0.17* |
| RFR + ELF exposed diabetic     | 7.09 ± 0.67* | 19.10 ± 1.71* | 2.60 ± 0.32* |

The values are means ± SD; n = 6. * shows statistically important results (p < 0.05) with respect to their own sham or control groups.

Table 3. Mean ± SD values of MDA, NO and GSH levels in kidney tissues

| Group                          | MDA (nmol/g) | NO (µmol/g) | GSH (nmol/g) |
|--------------------------------|--------------|-------------|--------------|
| Control                        | 4.15 ± 0.35  | 10.72 ± 1.60 | 2.17 ± 0.19  |
| Sham                           | 4.04 ± 0.24  | 10.00 ± 1.30 | 2.13 ± 0.14  |
| RFR exposed                    | 5.15 ± 0.51* | 11.47 ± 1.87 | 1.85 ± 0.20* |
| ELF exposed                    | 5.00 ± 0.54* | 12.19 ± 1.30* | 1.97 ± 0.15  |
| RFR + ELF exposed              | 5.45 ± 0.45* | 13.50 ± 1.30* | 1.87 ± 0.21* |
| Control diabetic               | 5.96 ± 0.46  | 15.64 ± 1.65 | 1.73 ± 0.20  |
| Sham diabetic                  | 4.96 ± 0.26  | 14.76 ± 1.97 | 1.73 ± 0.18  |
| RFR exposed diabetic           | 6.69 ± 0.32* | 14.24 ± 0.79 | 1.49 ± 0.09* |
| ELF exposed diabetic           | 5.96 ± 0.75  | 15.44 ± 1.83 | 1.72 ± 0.22  |
| RFR + ELF exposed diabetic     | 8.91 ± 0.90* | 17.65 ± 2.79 | 1.42 ± 0.20* |

The values are means ± SD; n = 6. * shows statistically important results (p < 0.05) with respect to their own sham or control groups.

Table 4. Mean ± SD values of MDA, NO and GSH levels in heart tissues

| Group                          | MDA (nmol/g) | NO (µmol/g) | GSH (nmol/g) |
|--------------------------------|--------------|-------------|--------------|
| Control                        | 3.62 ± 0.38  | 10.29±1.40  | 3.57 ± 0.29  |
| Sham                           | 3.42 ± 0.30  | 10.21±1.56  | 3.51 ± 0.26  |
| RFR exposed                    | 4.51 ± 0.07* | 13.26±1.27* | 3.19 ± 0.17* |
| ELF exposed                    | 3.85 ± 0.55  | 12.05±1.65  | 3.14 ± 0.16* |
| RFR + ELF exposed              | 4.64 ± 0.41* | 13.70±1.32* | 3.03 ± 0.14* |
| Control diabetic               | 5.00 ± 0.48  | 15.75±2.17  | 2.59 ± 0.18  |
| Sham diabetic                  | 4.90 ± 0.36  | 14.88±2.42  | 2.47 ± 0.15  |
| RFR exposed diabetic           | 5.98 ± 0.66* | 16.45±1.88  | 1.81 ± 0.26* |
| ELF exposed diabetic           | 5.28 ± 0.47  | 16.78±1.48  | 1.96 ± 0.23* |
| RFR + ELF exposed diabetic     | 6.86 ± 0.72* | 22.77±1.44  | 1.78 ± 0.29* |

The values are means ± SD; n = 6. * shows statistically important results (p < 0.05) with respect to their own sham or control groups.
In the present study, oxidative effects of ELF-MF and RFR on the diabetic and normal rats heart, liver, lung and kidney tissues were examined. There were different groups to see the possible effects of alone RFR exposure, alone ELF exposure and both frequency applications. The statistically most important change in the oxidative parameters were seen in the diabetic groups which received both exposures. Diabetic anomalies alone produce oxidative changes of tissues. However, if there is an extra electromagnetic exposure, this changes get exacerbated and could be reason to many critical health problems, such as cancer. A number of epidemiological studies indicate that there is a correlation between ELF electromagnetic field exposure and human health effects such as cancer (35), in particular childhood leukemia (36-37), or between wire code and cancer (38). Almost all of these epidemiological studies have considered residential and/or occupational ELF magnetic field exposure. ELF magnetic fields interact with living systems by two well established mechanisms: induced electric fields produced in accord with Faraday’s law of magnetic induction, and direct magnetic field effects on magnetic particles such as the crystals of magnetite (Fe₃O₄) that have been found in a number of organisms (39). A large number of other possible interaction mechanisms, including resonance effects, have been discussed. One of possible causal mechanism to explain ELF magnetic fields & cancer association; magnetic fields can reduce melatonin in both animals and humans (40-41). While reduced melatonin levels may increase the risk of cancer, the role of magnetic fields in mediating the reduction of melatonin affecting cancer is unproven. There are many oxidative effect studies about ELF-MF exposures.

The daily use of most of the communication devices i.e. mobile phones, results in chronic exposure to RFR. The interaction mechanism between the biological system and radio frequency radiation is not clear. RFR has thermal or and non-thermal effects on organisms. Both in vivo and in vitro studies found that tissue heating as a result of thermal effect by high level RFR exposure is the most commonly accepted mechanism of RFR for biological systems. Non-thermal effect mechanism means no increase in temperature observed, is another popular mechanism in recent years. There are a few studies carried out to examine the effects of RFR similar to the 3 G mobile phone on rats focusing on the oxidative stress.

Alkis et al. (25) investigated oxidative effects of mobile phones in brain tissue of rats. They showed increased MDA, NO and TOS level and decreased TAS level. They determined that the mechanisms of oxidative effects of mobile phones in the brain tissue might be associated with ROS. Pandey and Giri (21) investigated the influence of RFR on SOD and GSH-P. activities in testes tissues of mice. They found that RFR decreased the activities of antioxidant enzymes. Sabaan et al. (42) observed that RFR exposure has oxidative effects in brain and liver tissues of fetal and maternal rats. Gulati et al. (43) showed RFR has no oxidative or apoptotic effect on human lymphocytes cell culture. They also found that in vitro RFR exposure caused DNA damage. Devrim et al (44) investigated effects of RFR and vitamin C on antioxidant and oxidant parameters in different tissues (heart, ovary, liver and, kidney) and erythrocytes of rats. MDA, NO, and GSH-P levels in the erythrocytes increased significantly in the RFR group compared to the control group. It was observed that CAT activity and MDA level increased significantly, whereas ADA activities and NO levels decreased in the RFR group in the kidney tissues. However, in the heart tissues ADA, MDA, and NO activities significantly decreased in the exposed group. They concluded that RFR from mobile phones caused oxidative stress and peroxidation in the kidney tissues and erythrocytes of the rats. Vitamin C seems to have partial protective role against the oxidative stress in the erythrocytes.

In the recent study, we proved that ELF-MF, 2100 MHz RFR and both exposures lead to oxidative stress especially on diabetic rats. This induction mediated by increase of lipid peroxidation and the reduction of GSH. The study also showed that RFR could enhance NO production. Based on the findings of this study, we could say that ELF-MF and RFR are one of the environmental stressors and this fields can cause oxidative and nitrosative stress in lung, liver, kidney and heart tissues. Oxidative stress is a condition associated with many human diseases including myocardial infarction, neurodegenerative diseases, atherosclerosis, heart failure, chronic liver and lung diseases, etc. So, mobile phone usage should be limited, human being’s electromagnetic exposures should be controlled. The constant exposure of modern society to electromagnetic fields has raised considerable concerns about the potential risks to especially people who have chronic problems such as diabetes.

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