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EFFECTS OF RF AND ELF RADIATION ON OXIDATIVE STRESS OF BRAIN TISSUE AND PLASMA OF DIABETIC RATS

DİYABETİK SIÇANLARIN BEYİN DOKUSU VE PLAZMASINDA RF VE ELF RADYASYONUN OKSİDATİF STRES ÜZERİNDEKİ ETKİLERİ

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Abstract

Objective: Exposure to Radio Frequency (RF) and Extremely Low Frequency (ELF) radiation is increasing steadily with the progress of technology and industrialization. The aim of this study was to investigate whether RF and ELF radiation are oxidative stress effects in the plasma and brain tissue of diabetic and non-diabetic rats.
Methods: Experiment groups were designed as follows; C (control), S (sham), ELF (ELF radiation exposure), RF (RF radiation exposure), ELF+RF (ELF and RF radiation exposure), D-C (Diabetic Control), D-S (Diabetic Sham), D-ELF (Diabetic ELF), D-RF (Diabetic RF), D-ELF+RF (Diabetic ELF+RF). The experimental diabetes model was induced with a single dose of 65mg/kg streptozotocin (STZ). 2100 MHz RF and 50 Hz ELF radiation groups exposed for 1 month. Total nitric oxide (NOx), malondialdehyde (MDA) and total sulfhydryl groups (RSH) / glutathione (GSH) levels were measured in plasma and brain tissue.
Results: RF + ELF radiation exposure caused an increase in NOx and MDA levels in plasma and brain tissue of diabetic and non-diabetic rats (p<0.05). Exposure to RF and RF + ELF radiation caused a decrease in plasma RSH / tissue GSH levels in non-diabetic rats (p<0.05).
Conclusion: The most prominent effect was seen in the diabetic group with RF + ELF radiation exposure.

Keywords: *Diabetes, brain, plasma, radiofrequency radiation, very low frequency radiation, oxidant stress.*

Öz

Amaç: Teknolojinin ilerlemesi ve endüstrileşme ile birlikte hayatımızın hemen hemen her alanında yer alan RF ve ELF radyasyona maruziyet gittikçe artmaktadır. Çalışmadaki amacımız RF ve ELF radyasyonun diyabetik ve diyabetik olmayan sıçanların beyin doku ve plazmasında oksidatif strese etkilerini araştırmaktır.
Yöntem: Deney grupları; K (Kontrol), S (Sham), ELF (ELF manyetik alan maruziyeti), RF (RF Radyasyon maruziyeti), ELF+RF (ELF manyetik alan ve RF radyasyon maruziyeti), D-K (Diyabet Kontrol), D-S (Diyabet Sham), D-ELF (Diyabet ELF manyetik alan maruziyeti), D-RF (Diyabet RF radyasyon maruziyeti), D-ELF+RF (Diyabet ELF manyetik alan ve RF radyasyon maruziyeti) olarak tasarlandı. Deneysel diyabet modeli tek doz 65mg/kg Streptozotosin (STZ) ile oluşturuldu. RF radyasyon (2100 MHz) ve ELF (50 Hz) manyetik alan 1 ay boyunca, 20 dakika/gün, 5 gün/hafta olmak üzere uygulandı. Beyin doku ve plazmada toplam nitrik oksit (NOx), malondilaldehit (MDA) ve plazmada toplam sülfidril grupları (RSH) / dokuda glutatyon (GSH) düzeyleri bakıldı.
Bulgular: RF + ELF radyasyon maruziyeti, diyabetik olan ve olmayan sıçanların plazma ve beyin dokusunda NOx ve MDA düzeylerinde artışa neden oldu (p<0,05). RF ve RF + ELF radyasyonuna maruz kalma diyabetik olmayan sıçanlarda plazmada RSH / dokuda GSH düzeylerini azalttı (p<0,05).
Sonuç: En belirgin etki, diyabetik grupta RF + ELF radyasyon maruziyeti ile görüldü.

Anahtar Kelimeler: *Diyabet, beyin, plazma, radyofrekans radyasyon, çok düşük frekanslı radyasyon, oksidan stres.*

Introduction

Since the 1990s, radio frequency (RFR) and extremely low frequency (ELF) radiation resources have become an important research area for scientists as they are frequently used in everyday life. RFR sources include mobile phones, base stations, communication centers, microwave ovens, TV and radio transmitters and many others. RF field varies from 3 kHz to 300 GHz.[1,2] ELF sources include high voltage lines (YGH), transformers and electric devices that are used in homes and offices. The city current (50 Hz) used in all electronic devices at home include this frequency range. The city current is 50 Hz in Europe and 60 Hz in the USA.[3]

Human body has an advanced nervous system. Due to electrical activity in neural transport, the nervous system is thought to be highly sensitive to EM fields. The effects of EM fields on the nervous system and human behavior have been investigated for over 40 years, and especially in the past 20 years, scientists have concentrated their work on the effects of mobile phones and base stations on the human brain.[4]

Diabetes mellitus (DM) is a worldwide syndrome characterized by insulin build-up and release of impaired insulin response in tissues.[5] Numerous studies have demonstrated that oxidative stress and mitochondrial abnormalities are common to the etiologies of diabetes.[6,7] Because mitochondria are both targets and sources of ROS, oxidant-induced mitochondrial dysfunction may lead to an increased production of superoxide anion radicals by the electron transport chain.[8] High glucose and advanced glycation end products (AGEs) can initiate activation of the NADPH oxidase and trigger increased reactive oxygen species (ROS) generation, which may damage the structure and function of the brain.[9]

Glycation affects all of the body's proteins. Such as hemoglobin, albumin, insulin, immunoglobulins, low-density lipoproteins (LDL), and collagen. Other molecules with amino groups, including DNA, are also targeted by glycation.[10] Glycation of hemoglobin increases the amount of glycated hemoglobin (HbA1c) in circulation.[11]

ROS regulate many cellular events such as gene expression, differentiation, and cell proliferation. However, excessive production of ROS can cause cell damage by oxidizing DNA, lipid, and protein. Therefore, various antioxidants including glutathione (GSH), superoxide dismutase (SOD), catalase (CAT), and thioredoxin (Trx) exist to reduce ROS levels in cells. GSH is a main non-protein antioxidant in the cell, which supplies electrons for enzymes such as glutathione peroxidase (GPx). GSH is crucial for cell proliferation and apoptosis, which can protect cells from oxidative stress.[12,13]

Among free radicals, superoxide radical (O2.-), hydroxyl radical (OH.-) and nitric oxide radical (NO.) which is a kind of reactive nitrogen (RNS) are the most investigated types and have a significant role in diabetic cardiovascular complications.[14] Lipids in the membranes of intracellular organelles are highly sensitive to free radical damage. Lipid peroxidation, which occurs when free radicals react with lipids, can cause highly harmful effects. Damage caused by lipid peroxidation is extremely detrimental to the function of the cell.[15] Malondialdehyde (MDA) is the resultant damage to lipid peroxidation that occurs in the cell membrane. MDA is a commonly used marker for determining oxidative damage.[16]

Experimental *(in vitro / in vivo*) studies have shown that EM field and RF radiation exposure effects cell membrane function and cell metabolism.[17-20] It is known that EM field exposure leads to oxidative damage through its thermal effects. Recent studies have shown that non-thermal effects of EMF also cause oxidative damage. These effects usually emerge as a result of long-term absorption of EM radiation at low levels.[17] Along with the development of technology, diabetic individuals are exposed to RF radiation and ELF magnetic field for a long period of time. In chronic illnesses such as diabetes, the defense systems of cells weaken. They become more vulnerable to harmful environmental effects such as radiation. The studies that were performed reported that exposure to RFR deteriorated glucose metabolism[18], increased hemoglobin A1c levels[19] and constituted a risk factor for the development of diabetes. Havas M. suggests that ELF electromagnetic fields and RFR are responsible for the increasing rate of diseases such as diabetes, multiple sclerosis, chronic fatigue and fibromyalgia.[20] Studies on the effect of RF radiation and ELF magnetic fields on oxidative stress in brain tissue and plasma of diabetic individuals are limited. However, clues given by the existing studies indicate that exposure to radiation will effect diabetic individuals in a more adverse manner.

Because of these reasons, we aimed to investigate the effects of 2100 MHz RF electromagnetic field with an electric field intensity of 17.25 V / m and SAR value of 0.23 W / kg and 50 Hz - 8.2 mT ELF magnetic field exposure and the effects of simultaneous co-exposure to both radiations on oxidative stress and antioxidant levels in brain tissue and plasma of diabetic and non-diabetic rats.

Methods

Sixty adult male Wistar Albino rats were used in the study (weighing 250±20 g, 12-16 weeks old). Each of the rats was housed in separate cages. They were kept in an environment of controlled temperature (24±2ºC), humidity (30-45%) and a light-dark cycle for 12 hours. Rats were fed ad libitum with standard rat diet and tap water. Cage cleaning was done every day, with the replacement of the sawdust, and the cage was allowed to remain dry. All animal management and handling procedures, in addition to the study design, were approved by the university ethical and research committee (Approval No: G.Ü.ET-11.071).

The rats were randomly separated into 10 groups of 6 animals each group. Experiment groups were designed as follows; C (control), S (sham), ELF (ELF magnetic field exposure), RF (RF radiation exposure), ELF+RF (ELF magnetic field and RF radiation exposure), D-C (Diabetic Control), D-S (Diabetic Sham), D-ELF (Diabetic group with ELF magnetic field exposure), D-RF (Diabetic group with RF radiation exposure), D-ELF+RF (Diabetic group with ELF magnetic field and RF radiation exposure). Rats of the healthy and diabetic cage-control groups were housed in their home cages during the entire experimental period without being subjected to any experimental manipulation. Sham groups were subjected to the same exposure procedures in the exposure systems without ELF magnetic field source and RF generator exposures.

All animals were weighed following an 8 hour fasting before starting the experiment and fasting blood glucose was measured by taking blood from the tail vein.

Animals were injected intraperitoneally with a single dose of 65 mg/kg Streptozotocin (STZ) dissolved in 1 ml of cold citrate buffer 0.1 M (pH 4.5).[21] Fasting blood sugars of animals fasted for 8 hours after 48 hours of STZ injection were determined. Those with open blood glucose levels above 250 mg/dl were considered diabetics and these animals were separated.[21] Control groups were given i.p. 1 mL, STZ

solvent citrate buffer injection. We waited for about 1 month for the stabilization of diabetes. After the occurrence of diabetes, the rats were followed up for 2 months with blood sugar measurement twice a week.

Rohde & Schwarz (Rohde & Schwartz, SMBV100A, Germany) signal generator was used as RF signal source[22] (Figure 1), ETS Lindgren 3164-04 (ETS Lindgren, Model 3164-03, USA) horn antenna was used for field propagation and Helmholtz Coil System was used for ELF applications [23] (Figure 2). 2100 MHz Radio Frequency and 50 Hz Very Low Frequency Radiation were applied to the magnetic field groups for 1 month, 20 minutes/day, 5 days/week. The animals in the sham group were kept in the exposure environment when the RF and ELF radiation sources were in the closed position.

Rats were anesthesied with xylasine (5 mg/kg) + ketamine (45 mg/kg). Blood samples were collected under anesthesia, after blood collection rats were sacrificed and brain tissues were taken. Brain tissues and separated plasma stored at -80C until working.

Plasma and brain NOx levels were assayed based on vanadium chloride and griess reaction methods at 540 nm by using ELISA.[24] Brain tissue lipid peroxidation was quantified by measuring the formation of thiobarbituric acid reactive substances (TBARS). The absorbance of the samples was measured at 535 nm.[25]

Figure 1. RF Radiation exposure system[22]

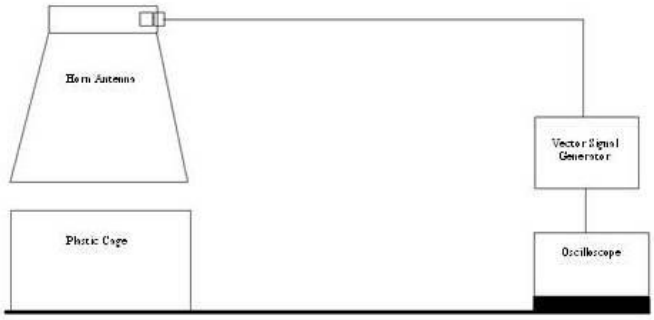
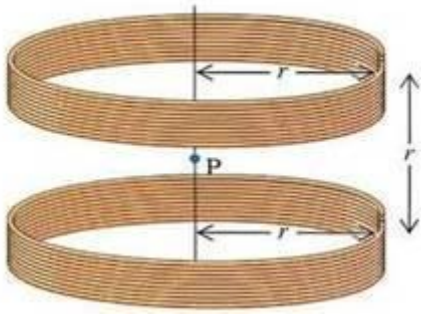


Figure 2. ELF Radiation exposure system[23]



Plasma lipid peroxide levels were estimated by the method of Kurtel et al.[26] Briefly, lipid peroxidation was quantified by measuring the formation of TBARS. The absorbance of each sample was determined at 532 nm. Lipid peroxide levels are expressed in terms of MDA equivalents using an extinction coefficient of $1.56 \times 105\ l \cdot mol–1 \cdot cm–1$.[27]

The brain tissue GSH levels were determined by Ellman method with some modifications.[28] The plasma RSH levels were determined by the method of Kurtel et al.[26] The absorbance of each sample was determined at 412 nm.

Statistical Analysis

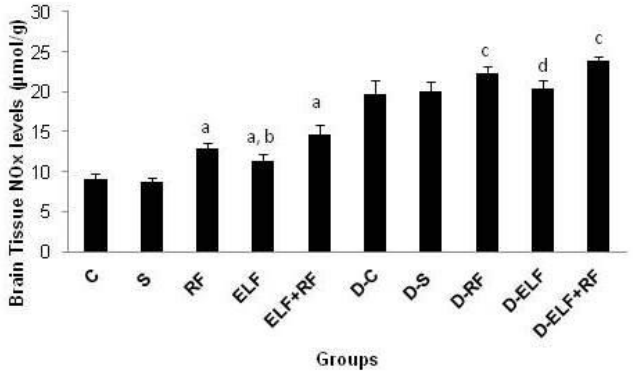
All data are expressed as the mean ± standard deviation (SD). Data were analyzed by using Statistical Package for Social Sciences 15.0 software program. Comparisons among groups were performed using one-way analysis of variance, followed by post hoc Dunnett test. $p<0.05$ is considered statistically significant.

Results

There were no differences between the Control and Sham groups of diabetic and non-diabetic groups regarding brain tissue NOx levels ($p>0.05$). RF exposure caused an increase in brain tissue NOx levels of diabetic and non-diabetics ($p=0.002$; $p=0.00$, respectively). No increase was observed in brain tissue NOx levels of diabetics that were exposed to ELF ($p>0.05$). NOx levels in the non-diabetic group that was exposed to ELF increased ($p=0.015$).

RF+ELF exposure caused in increase in NOx levels of both diabetic and non-diabetic groups ($p=0.00$). The most significant increase in NOx levels was found in the diabetic group with RF+ELF exposure (Figure 3).

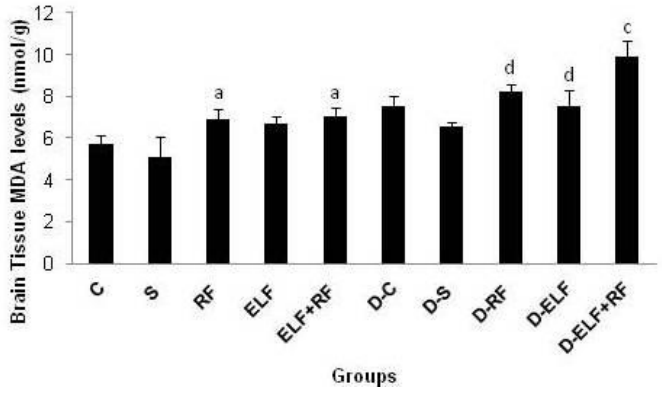
Figure 3. Brain tissue NOx levels (μmol/g)



Values were given as mean ± SD; n = 6.
a: $p<0.05$ versus C and S) ; b: $p<0.05$ versus ELF+RF)
c: $p<0.05$ versus D-C and DS); d: $p<0.05$ versus D-RF+ELF)
Diabetic groups were significant difference compared to their control groups.
Comparisons among groups were performed using one-way analysis of variance, followed by post hoc Dunnett test. $p<0.05$ is considered statistically significant.
C (control), S (sham), ELF (ELF radiation exposure), RF (RF radiation exposure), ELF+RF (ELF and RF radiation exposure), D-C (Diabetic Control), D-S (Diabetic Sham), D-ELF (Diabetic+ELF radiation exposure), D-RF (Diabetic+RF radiation exposure), D-ELF+RF (Diabetic+ELF and RF radiation exposure)

There were no differences between brain tissue MDA levels of the Control and Sham groups of diabetic and non-diabetic groups ($p>0.05$). RF exposure caused an increase in brain tissue MDA levels in the non-diabetic group ($p=0.016$) but did not cause an increase in the diabetic group ($p>0.05$). ELF exposure did not cause an increase in brain tissue MDA levels of diabetics and non-diabetics ($p>0.05$). RF+ELF exposure caused an increase in brain tissue MDA levels of both diabetics and non-diabetics ($p=0.00$; $p=0.008$, respectively). The greatest increase in MDA levels was found in the diabetic group with RF+ELF exposure in brain tissue (Figure 4).

Figure 4. Brain tissue MDA levels (nmol/g)

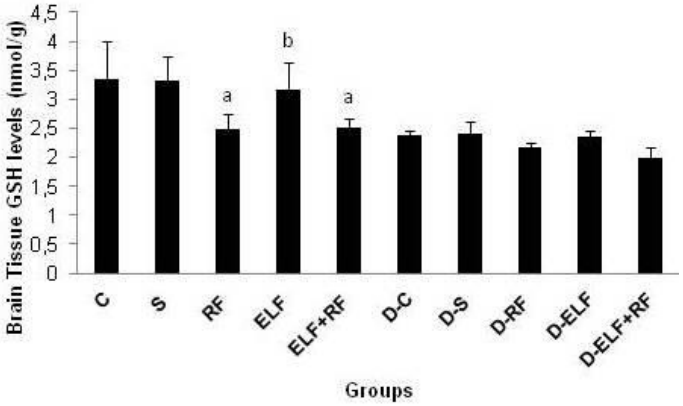


Values were given as mean ± SD; n = 6.

a: $p<0.05$ versus C and S) ; c: $p<0.05$ versus D-C and D-S)
d: $p<0.05$ versus D-RF+ELF)
Diabetic groups were significant difference compared to their control groups.
Comparisons among groups were performed using one-way analysis of variance, followed by post hoc Dunnett test. $p<0.05$ is considered statistically significant.
C (control), S (sham), ELF (ELF radiation exposure), RF (RF radiation exposure), ELF+RF (ELF and RF radiation exposure), D-C (Diabetic Control), D-S (Diabetic Sham), D-ELF (Diabetic+ELF radiation exposure), D-RF (Diabetic+RF radiation exposure), D-ELF+RF (Diabetic+ELF and RF radiation exposure)

No differences were observed between brain tissue GSH levels of the Control and Sham groups of diabetic and non-diabetic groups ($p>0.05$). RF exposure caused a decrease in brain tissue GSH levels in non-diabetics ($p=0.001$) but did not cause a change in diabetics ($p>0.05$). ELF exposure did not cause a change in the brain tissue of diabetics and non-diabetics ($p>0.05$). RF+ELF exposure caused a decrease in brain tissue GSH levels in non-diabetics ($p=0.001$) but it did not cause any change in diabetics ($p>0.05$) (Figure 5).

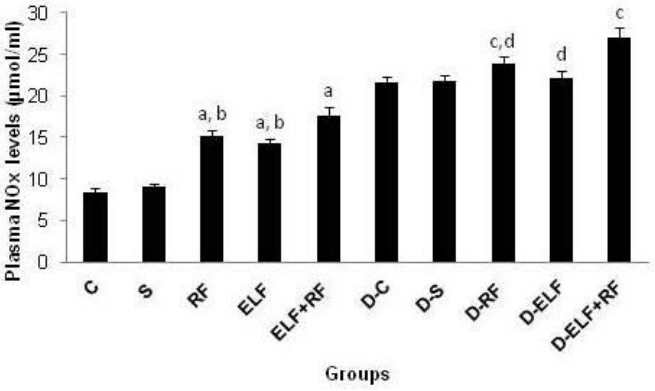
Figure 5. Brain tissue GSH levels (nmol/g)



Values were given as mean ± SD; n = 6.
a: $p<0.05$ versus C and S) ; b: $p<0.05$ versus ELF+RF)
Diabetic groups were significant difference compared to their control groups.
Comparisons among groups were performed using one-way analysis of variance, followed by post hoc Dunnett test. p<0.05 is considered statistically significant.
C (control), S (sham), ELF (ELF radiation exposure), RF (RF radiation exposure), ELF+RF (ELF and RF radiation exposure), D-C (Diabetic Control), D-S (Diabetic Sham), D-ELF (Diabetic+ELF radiation exposure), D-RF (Diabetic+RF radiation exposure), D-ELF+RF (Diabetic+ELF and RF radiation exposure)

No differences were observed between the plasma NOx levels of the Control and Sham groups of diabetic and non-diabetic groups ($p>0.05$). In non-diabetic groups RF, ELF, and RF+ELF radiation exposure increased NOx levels in the plasma ($p=0.00$). While RF and RF+ELF exposure caused an increase in diabetics, ($p=0.001$; $p=0.00$ respectively), ELF exposure did not cause any changes ($p>0.05$). RF + ELF radiation exposure resulted in a more marked increase NOx levels in plasma (Figure 6).

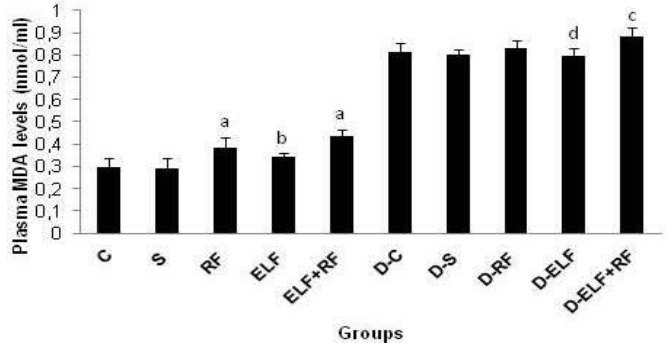
Figure 6. Plasma NOx levels (µmol/ml)



Values were given as mean ± SD; n = 6.
a: $p<0.05$ versus C and S) ; b: $p<0.05$ versus RF+ELF) ;
c: $p<0.05$ versus D-C and D-S) ; d: $p<0.05$ versus- D-RF+ELF)
Diabetic groups were significant difference compared to their control groups.
Comparisons among groups were performed using one-way analysis of variance, followed by post hoc Dunnett test. $p<0.05$ is considered statistically significant.
C (control), S (sham), ELF (ELF radiation exposure), RF (RF radiation exposure), ELF+RF (ELF and RF radiation exposure), D-C (Diabetic Control), D-S (Diabetic Sham), D-ELF (Diabetic+ELF radiation exposure), D-RF (Diabetic+RF radiation exposure), D-ELF+RF (Diabetic+ELF and RF radiation exposure)

No differences were observed in plasma MDA levels between the Control and Sham groups of the diabetic and non-diabetic groups ($p>0.05$). RF exposure caused an increase in plasma MDA levels in non-diabetics ($p=0.003$) but did not cause any changes in diabetics ($p>0.05$). ELF exposure did not cause any changes in diabetics and non-diabetics ($p>0.05$). RF+ELF exposure increased plasma MDA levels in diabetics and non-diabetics ($p=0.023$; $p=0.00$, respectively). RF+ELF radiation exposure resulted in a more marked increase MDA levels in plasma in diabetics (Figure 7).

Figure 7. Plasma MDA levels (nmol/ml)

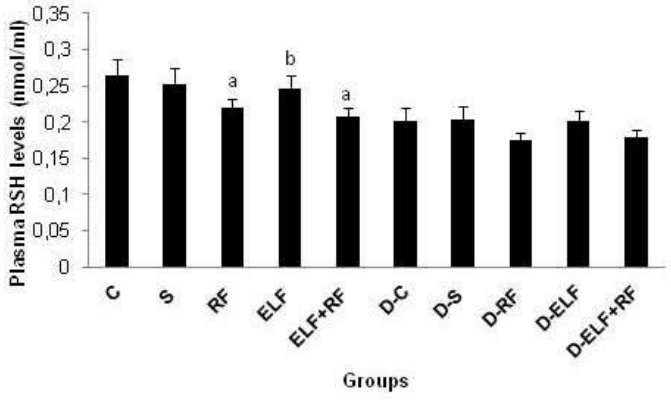


Values were given as mean ± SD; n = 6.
a: $p<0.05$ versus C and S) ; b: $p<0.05$ versus RF+ELF) ;

c: $p<0.05$ versus D-C and D-S) ; d: $p<0.05$ versus D-RF+ELF)
Diabetic groups were significant difference compared to their control groups.
Comparisons among groups were performed using one-way analysis of variance, followed by post hoc Dunnett test. $p<0.05$ is considered statistically significant.
C (control), S (sham), ELF (ELF radiation exposure), RF (RF radiation exposure), ELF+RF (ELF and RF radiation exposure), D-C (Diabetic Control), D-S (Diabetic Sham), D-ELF (Diabetic+ELF radiation exposure), D-RF (Diabetic+RF radiation exposure), D-ELF+RF (Diabetic+ELF and RF radiation exposure)

No differences were observed in plasma RSH levels between the Control and Sham groups of diabetic and non-diabetic groups ($p>0.05$). RF and RF+ELF exposure caused a decrease in plasma RSH levels in non-diabetics ($p=0.001$; $p=0.00$, respectively). ELF exposure did not cause any changes ($p>0.05$). RF, ELF and RF+ELF exposure did not cause any changes in plasma RSH levels of diabetics ($p>0.05$) (Figure 8).

Figure 8. Plasma RSH levels (nmol/ml)



Values were given as mean ± SD; n = 6.
a: $p<0.05$ versus S-C) ; b: $p<0.05$ versus RF+ELF)
Diabetic groups were significant difference compared to their control groups.
Comparisons among groups were performed using one-way analysis of variance, followed by post hoc Dunnett test. $p<0.05$ is considered statistically significant.
C (control), S (sham), ELF (ELF radiation exposure), RF (RF radiation exposure), ELF+RF (ELF and RF radiation exposure), D-C (Diabetic Control), D-S (Diabetic Sham), D-ELF (Diabetic+ELF radiation exposure), D-RF (Diabetic+RF radiation exposure), D-ELF+RF (Diabetic+ELF and RF radiation exposure)

Discussion

Today, our exposure to RF and ELF radiation which take part in almost every aspect of our life is increasing. There are various studies on the effects of such radiation on the body and our study is important for the application of RF and ELF radiation exposure at the same time and in diabetic rats. The aim of this study was to investigate whether RF and ELF radiation have oxidative stress effects on the plasma and brain tissue of diabetic and non-diabetic rats.

In this study, diabetes was induced by injecting 65 mg/kg STZ. 2 months later, brain tissue MDA, NOx and GSH levels and plasma MDA, NOx and RSH levels were examined. When each diabetic group was compared with its own control group, it was observed that brain tissue and plasma MDA and NOx levels increased while GSH/RSH levels decreased.

The results of the studies in literature support our study. Nurdina et al. found that levels of MDA in the brain increased while the levels of GPx and SOD decreased after 60 mg/kg STZ injection.[29] Shivavedi et al. examined the brain tissues of rats with diabetes that they formed by injecting STZ at 65 mg/kg and they showed that MDA levels increased, CAT and SOD levels decreased in brain tissues of rats.[30] Moneim et al., who produced diabetes at similar doses, found that MDA and NOx levels increased and CAT, SOD, GPx and GSH levels decreased in brain tissue.[31] Xie et al. showed that MDA levels increased and SOD levels decreased in brain tissues of diabetes induced rats with 80 mg/kg STZ injection. In contrast to other studies, they found an increase in GPx and CAT levels.[32]

In our study, male rats were exposed to 50 Hz - 8.2 mT ELF magnetic field for one month, 20 min/5 days/ week. According to our study, 50 Hz ELF radiation increased brain tissue and plasma NOx levels in non-diabetics but did not change MDA and GSH/RSH levels. It did not cause any changes in brain tissue and plasma MDA, NOx and GSH/RSH levels.

Our investigations show that studies in which 50 Hz ELF radiation is applied are very limited in the literature. On the contrary to our findings; Samano et al. found an increase in MDA levels while CAT, SOD, NO and GSH levels of brain tissue decreased in rats exposed to an electromagnetic field of 60 Hz 2.4 mT for 120 minutes.[33]

In Seyhan and Guler's study, guinea pigs were exposed to 50 Hz, 1,35 kV/m radiation for 8 hours for 1,3,5,7 and 10th day and they found that MDA and SOD levels in kidney, lung, liver tissue and plasma increased about 2 times on the 3rd and 5th days of the study and about 3 times on the 10th day of the application. These studies show that adverse effects in biological systems can also change according to the duration of exposure.[34] Cho et al. observed that NO levels in brain tissue of rats increased significantly by being exposed to ELF radiation at 60 Hz for 5 days.[35]

In this study, RFR at a frequency of 2100 MHz, an electric field intensity of 17.25 V / m and a SAR value of 0.23 W / kg for 1 month, 20 min/5 day /week caused an increase in brain tissue and plasma MDA and NOx levels and a decrease in GSH/RSH levels in non-diabetics._While it increased brain tissue and plasma NOx levels, it did not cause any change in MDA and GSH/RSH levels in diabetics. There are studies in the literature showing that RF electromagnetic field exposure increases oxidant stress in brain tissue and plasma and decreases antioxidant levels, with different protocols being applied. For instance, Gumral et al. observed that exposure to 2450 MHz electromagnetic radiation for 60 minutes a day for 30 days increased lipid peroxidation while it did not make a difference in GSH and GPx levels in rat erythrocytes.[36] Gürler et al., who applied a similar experimental protocol, found that EM Radiation did not make a difference in MDA levels in brain tissue and plasma in rats but increased levels of advanced oxidation protein product (AOPP) and 8-hydroxydeoxyguanosine (8-OHdG).[37] Altun et al. found a reduction in the number of hippocampus and pyramidal cells of rats exposed to an electromagnetic field of 900 MHz for 60 minutes a day for 15 days. In contrast, radiation exposure increased the production of free radicals in the serum and consequently reported that these radicals cause an increase in antioxidant enzyme activity such as SOD, CAT and GSH.[38] Kıvrak et al. observed that exposure to 900-MHz EMF radiation once daily over 21 days (60 min/day) decreased the number of Granular and Purkinje cell. Furthermore, radiation exposure caused an increase in CAT activity due to increased free radicals.[39]

There are no studies in literature that report the direct effects of radiation exposure on rats. However, the studies that were

performed indicate that radiation exposure is a risk factor for the development of diabetes. In their study, Salah et al. reported that exposure to RFR 2.45 GHz, 1 h/day during 21 consecutive days decreased the activities of GPx, CAT and the SOD and groups thiol amount, respectively in liver and kidneys. Indeed, exposure to RF increased the MDA concentration respectively in liver and kidneys. Besides, the exposure of rats to RF induced a diabetes-like status by deteriorating glucose metabolism.[18] In another study, it was stated that the exposure of 12-16 years of age of students to 9.601 nW/cm2 at frequency of 925 MHz RFR for 1 week, 5 days a week, 6 hours a day increased Hemoglobin A1c levels and that RFR is a risk factor for diabetes.[19]

In the literature, there is no study examining the effect of simultaneous exposure to RF+ELF on any diabetics or non-diabetics tissue. Therefore, the results of our radiation exposure are significant in terms of being the first study in this area. In our study, simultaneous exposure to RF+ELF caused an increase in brain tissue and plasma MDA and NOx levels in diabetics and non-diabetics. While GSH/RSH levels decreased in non-diabetics, they did not change in diabetics. In our study, the effects on brain functions were not studied directly but in the light of studies showing the negative effects of RF and ELF radiation on brain functions, we can say that increased oxidant stress in brain tissue and decreased antioxidant defenses suggest that nervous system functions may also be negatively affected in our experimental groups. However, the effects of EM radiation on biological systems are not limited with cell membranes and oxidant-antioxidant defense system. In literature, the effects of EM radiation on neuronal electrical activity, energy metabolism, genomic responses, neurotransmitter balance, blood–brain barrier permeability, cognitive function, sleep, and various brain diseases including brain tumors have also been investigated.[40] Individuals with a chronic disease with increased oxidative stress may suffer more from the effects of radiation. When the data in our study and literature are examined, ELF and RF radiation seem to require more detailed work to explain the effects on the nervous system, especially in diabetic individuals with high sensitivity.

Conclusion

In conclusion, ELF, RF ve ELF+RF radiation increases oxidative stress in brain tissue and plasma in non-diabetics. Increased oxidative stress in diabetics becomes more severe with exposure to RF and RF+ELF radiation. The most marked effect was seen in the diabetic group in which both RF+ELF radiation were applied. This finding suggests that diabetic animals are more affected by radiation than healthy animals. Our findings in diabetic animals suggest that the adverse effects of ELF and RF radiation on the nervous system may be much greater.

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Conflict of Interest

The authors have no conflicts of interest to disclose.

Compliance with Ethical Statement

All animal management and handling procedures, in addition to the study design, were approved by the university ethical and research committee (Approval No: G.Ü.ET-11.071).

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Author Contributions

Study idea/Hypothesis: DK, BSA, ÇÖ; Data preparation: DK, BSA; Analysis: DK, BSA; Literature review: DK, BSA; Manuscript writing: DK; Critical Review: DK

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