Possible Effect of 2100 Mhz Cell Phone Radiation on Heart and Spleen Tissues of Rats

2100 Mhz Cep Telefonu Radyasyonun Sıçan Kalp ve Dalak Dokularına olası Etkileri

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ABSTRACT

Introduction: The widespread access of the society to mobile phones and their intensive use cause health concerns. This study is aimed to investigate the possible histopathological effects of exposure to Radio-frequency Radiation (RFR) originating from mobile phones rat heart and spleen tissue.
Methods: Totally 14 Sprague Dawley male rats were used and divided into 2 group (n= 7 for each); sham-control group, exposure group. RFR exposure group was exposed to 2100 MHz GSM-like RFR for 5 hours/day, for 14 days. Heart and spleen tissues of all rats were sampled for histopathological examination and hematoxylin-eosin staining was performed. For p53 examination, immunohistochemical staining was also used in both tissues.
Results: Histopathological and immunohistochemical evaluation revealed no significant changes in heart tissue, but trabecular irregularity and enlargement of sinusoids were observed in the spleen in histopathological evaluation.
Conclusion: It was observed that short-term RFR exposure did not cause significant morphological changes in heart and spleen tissue. This situation may be seen due to the protective effect of the body against RFR.

Key Words: Mobile phone, spleen, radio-frequency radiation, heart, rat

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ÖZET

Amaç: Toplumun cep telefonlarına erişiminin yaygınlaşması ve yoğun kullanımı sağlık sorunlarına neden olmaktadır. Bu çalışmanın amacı, cep telefonlarından kaynaklanan radyofrekans radyasyona maruziyetin sıçan kalbi ve dalak dokusu üzerindeki olası histopatolojik etkilerini araştırmaktır.
Yöntem: Çalışmamızda toplam 14 Sprague Dawley erkek sıçan kullanıldı. Sıçanlar 2 gruba ayrıldı; sham-kontrol (n = 7) ve maruziyet grubu (n = 7). Deney grubu 14 gün boyunca günlük 5 saat, 2100 MHz GSM-like radyofrekans radyasyon maruziyetinde tutuldu. Tüm ratların kalp ve dalak dokuları histopatolojik inceleme için örneklendi ve ardından hematoksilen-eosin boyama yapıldı. Ayrıca her iki dokuda da p53 immünohistokimyasal boyamasına başvuruldu.
Bulgular: Histopatolojik ve immünohistokimyasal değerlendirmede kalp dokusunda önemli bir değişim gözlemlenmezken ve dalakta histopatolojik olarak trabeküllerde düzensizlik ve sinüzoidlerde genişleme gözlendi.
Sonuç: Sıçanlara uygulanan kısa süreli cep telefonu kaynaklı radyofrekans radyasyonun kalp ve dalak dokusunda önemli morfolojik değişikliklere neden olmadığı görüldü. Bu durum radyofrekans radyasyona karşı vücudun savunma mekanizmasının devreye girmesinden kaynaklı olabilir.

Anahtar Sözcükler: Cep telefonu, dalak, elektromanyetik radyasyon, kalp, sıçan

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INTRODUCTION

The use of mobile phones is increasing every day in the world. Radio-frequency radiation (RFR) has been found effective on children's cognitive / behavioral situation and affective also in animal cells in recent study reports. Informative guidelines on the public health effects of mobile phone use are needed (1). RFR can cause morphological changes in different living systems of rats (2). Therefore, it is necessary to provide potential health risk information for users in order to be protected from RFR emitted from mobile and wireless devices (3). RFR have reported that they have such effects on carcinogenicity, geno-toxicity, mutagenicity, neurodegenerative diseases, neuro-behavioral problems and oxidative stress increases, nervous, circulatory, immune, endocrine and skeletal systems (4). The number of base stations is increasing with the widespread use of mobile phones and mobile telecommunication techniques. Higher base station numbers in rural environments may cause potential hazard to living things related to exposure to RFR (5). Considering the increasing popularity of mobile phones, short and long-term studies are required to determine the possible adverse effects of using and transporting them closer to body parts (6). It has been reported that the RFR applied prenatally has pathological and biochemical effects on the development of the rat spleen, as well as causing oxidative stress and histopathological changes in the heart tissue of male mouse pups (7,8). Here, we report the possible effects of 2100 MHz RFR on rat heart and spleen tissue for a short exposure.

METHODS

Animals

Sprague Dawley male rats were obtained from Gazi University Experimental Research and Animal Laboratory for the study. All processes in the study were carried out according to the Guidelines for the Care and Use of Laboratory Animals (G.Ü.ET-20.026). Animals were divided into two groups; sham-control group (n=7) and RFR exposure group (n=7, 2100 MHz RFR), respectively. RFR exposure group was exposed for 5 hours/day, for 14 days. The study was performed under normal laboratory conditions (12 hours light / night, 21-23 ° C room temperature, 45-50 humidity range, normal water and pellet feed).

Radio-frequency Radiation and SAR calculation

A signal generator (Rohde & Schwartz, SMBV100A, Germany) and an horn antenna (ETS-Lindgren Horn, Germany) were used to generate RFR like mobile phone radiation. For the frequency of 2100 MHz, the average electric field was measured 38.95 V/m with Narda EMR 300 electromagnetic field measurement device, both the exposure group and the sham-control groups were taken into plexiglass cages (40 X 25 X 10 cm) (length X width X depth). Only the exposure group was exposed to RFR exposure. Figure 1 shows the experimental procedure. Heart tissue SAR values at 2100 MHz are calculated as 243 mW/kg and 661 mW/kg for 10g and 1g averaging, respectively. Spleen tissue SAR values at 2100 MHz are calculated as 209 mW/kg and 671 mW/kg for 10g and 1g averaging, respectively. Commercial electromagnetic field solver based on Finite Integration Techniques was used for SAR calculations. 3D volumetric pixel model of a rat was used in SAR calculations. The SAR values obtained are shown in table 1 (9).

Table 1 SAR values of tissues

Body part-SAR	10g	1g
Whole body	305.5 mW/kg	720 mW/kg
Heart	243 mW/kg	661 mW/kg
Spleen	209 mW/kg	671 mW/kg

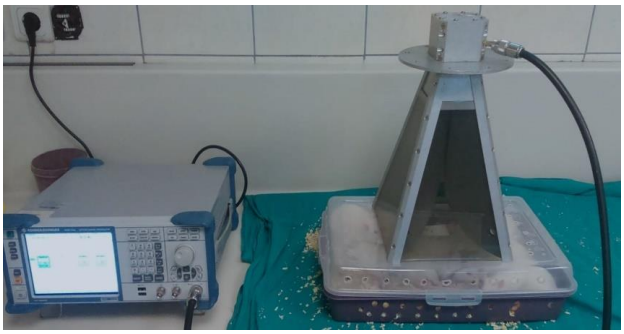


Fig 1 Exposure system

Macroscopic evaluation of heart and spleen

Heart and spleen tissues were taken from the anesthetized rats and taken into %10 neutral-buffered formalin. All of the samples sliced to the long axis were followed up for 1 night for histopathological examination.

Histopathological evaluation of heart and spleen

Heart and spleen tissues were taken from the anesthetized rats and taken into formol. After the tissues were embedded in paraffin blocks, they were cut at a thickness of 4 micrometers and stained with hematoxylin and eosin (H&E). LCA (leukocyte common antigen) immunohistochemical staining was performed to determine the inflammation (lymphocyte) density, and Masson's trichrome histochemical staining was performed to determine the fibrosis in heart tissues. Additionally, in both heart and spleen tissues, p53 immunohistochemical staining was performed (0: no staining, 1: focal staining (1-5%), 2: moderate staining (6-10%) 3: diffuse staining (more than 10%)). The percentage of positive cells was estimated, counting 1000 cells per case. Histopathological findings were evaluated under a light microscope (CX41, Olympus, Tokyo, Japan).

Histopathological scoring was interpreted according to the highest area. By making semi-quantitative analysis; 3 categories (0: None, 1: Mild/focal, 2: Moderate, 3: Severe/diffuse) were determined and the parameters were scored accordingly. Scoring of parameters "fibrosis, inflammation, mast cell infiltration, myocardial degeneration, myocyte necrosis, vascular leakage/damage, thrombus" was used for heart tissue (10,11). For the spleen tissue, parameters of "congestion in the red pulp, central venule loss in the white pulp, irregularity in trabeculae, dilatation in sinusoids, hemosiderin accumulation" were evaluated in terms of scoring (10).

Statistical Analysis

Statistical analysis of the study was done using Statistical Package for Social Sciences version 21.0 software for Windows (IBM SPSS, USA). For comparisons of the histopathological scores of the two groups, Mann-whitney-U test was used. Data are expressed as median (min, max). P value < 0.05 was considered statistical significant.

RESULTS

Sections taken from the heart and spleen tissues of all groups were stained with H&E and analyzed histopathologically under a light microscope. The sections of the heart tissue of the sham-control and exposure groups were compared. Figure 2 and Table 2 show the results obtained from the sham-control and exposure groups. Mast cell infiltration and microhemorrhage foci between the myocytes were detected more intense in the exposure group (Fig 2). No histopathological findings were found between the sham-control and exposure groups in the scoring for heart tissue (Table 2).

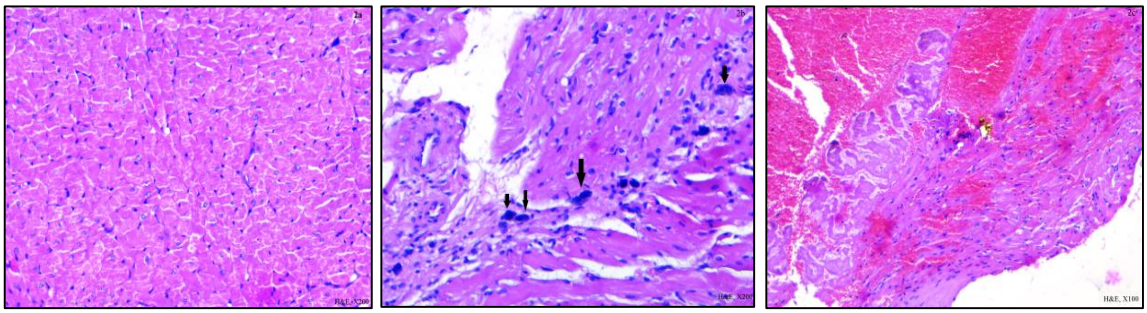


Fig2a. The usual appearance in myocytes in the rat heart of the control group (H&E, X200)
Fig2b. Mast cells in the rat heart of the exposure group (arrow: mast cells) (H&E, X200)
Fig2c. Microhemorrhage focus among the myocytes in the rat heart of the exposure group (H&E, X100)

Table 2 Histopathological scoring of heart tissue in rats (median, min and max)

	Inflam-mation	Mast cell infiltrati-on	Myocardial degeneration	Myocyte necrosis	Thrombus	Vascular leakage / damage	p53
Sham-Control	0 (0-0)	1 (1-2)	0 (0-0)	0 (0-0)	1 (0-2)	0 (0-0)	1 (0-1)
Exposure group	0 (0-1)	1 (1-2)	0 (0-0)	0 (0-0)	1 (0-2)	0 (0-3)	0 (0-1)
Mann-Whitney U	21.000	17.500	24.500	24.500	18.500	14.000	21.000
*P-value**	0.317	0.254	1.00	1.00	0.389	0.062	0.606

* No significant variation was detected between the control and exposure groups of all parameters.

The sections of the spleen tissue of the sham-control and exposure groups were compared. Figure 3 and Table 3 show the results obtained from the sham-control and exposure groups. In the exposure group of rat spleen tissue, a slightly irregular appearance was detected in the trabeculae (Fig 3).

In the scoring made for splenic tissue, only a significant change was found in the parameters of irregularity in the trabeculae and dilation in sinusoids between the sham-control and exposure groups (Table 3).

Table 3 Histopathological scoring of spleen tissue in rats (median, min and max)

	Central venule loss in white pulp	Irregularity in the trabeculae	Dilation in sinusoids	Hemosiderin accumulation	p53
Sham-control	0 (0-0)	0 (0-1)	1 (0-1)	0 (0-1)	2 (0-2)
Exposure group	0 (0-0)	1 (0-1)	1 (1-2)	0 (0-0)	2 (0-2)
Mann-Whitney U	24.500	10.500	12.000	21.000	21.500
P-value	1.00	0.037*	0.044*	0.317	0.653

*p < 0.05 significant different compared to control

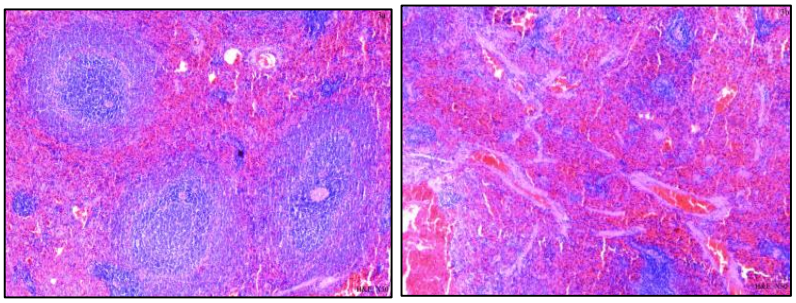
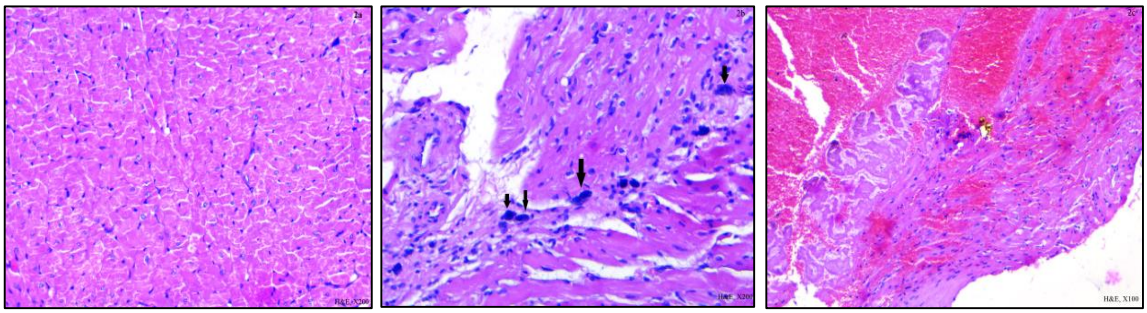


Fig3a. The white pulp and red pulp around the rat spleen of the sham-control group (H&E, X50)
Fig3b. Irregular appearance in trabeculae of the rat spleen of the exposure group (H&E, X50

DISCUSSION

There are studies that investigated the effects of RFR on living tissues and reported that RFR cause an increase in oxidative stress parameters by changing the antioxidant balance of tissues/cells (12,13,14). Chronic RFR exposure has been reported to cause an increased apoptotic response in living tissue (26).

It has been stated that as a result of exposure to RFR, dysfunction and histopathological changes in the functions of the cardiovascular system organs of humans and animals could be found (15). However, up to the effects of RFR on biological things are fully investigated, it is important to pay attention to the exposure of these fields (16). Kıray et al. reported that exposure to 3 mT 50 Hz electromagnetic field 4 hours a day every day for two months may cause morphological damage to the myocardium of adult rats (17).



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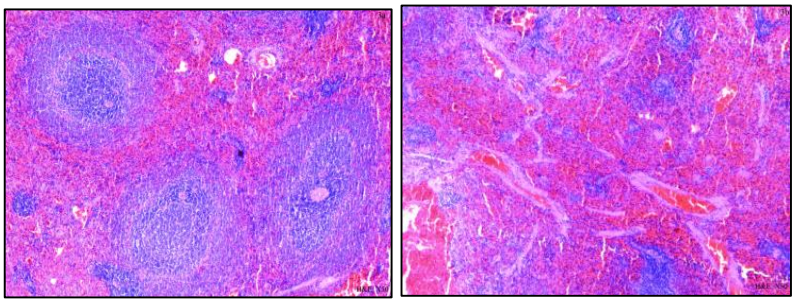

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In another study, it has been suggested that the ELF magnetic field (60 minutes, 7 mT and 40 Hz per day) on 14 days exposure may reduce the antioxidant capacity by affecting the formation of reactive oxygen species (18). 1800 MHz RFR exposure has been shown to cause irregularity and distortion of heart muscle fibers in the rat heart (2). It has been reported that 1 hour exposure of 900 MHz causes structural changes in male adolescent rat heart tissue (19). It has been reported by researchers that 2100 MHz RFR for eight weeks (5 days a week, 60 minutes a day) has some negative effects in terms of oxidative stress and antioxidants in heart tissue, and it has some degenerative effects in heart tissue (20).

In the present study, it has been investigated whether there was a difference in inflammation, mast cell infiltration, myocardial degeneration, myocyte necrosis, thrombus, vascular leakage / damage parameters in the control and exposure groups for heart tissue by histopathological and p53 immunohistochemical staining. As a result of our observations, no difference was observed. In the exposure group, mast cell infiltration and microhemorrhage foci were noted among myocytes. In the literature data, they reported negative reports in long-term studies of RFR on heart tissue. In this study, it is seen that the short-term RFR did not have a significant effect. This may because of the exposure time and intensity of RFR.

It has been reported that rats exposed to whole body radiation for 2 hours a day for 35 days have adverse effects on the histology of the spleen tissue (10). It has been reported that megakaryocytes, enlarged white pulp and dilated sinusoids were observed in rat splenic tissues of 1 hour daily 900 MHz RFR exposure for 21 days (21). It has been emphasized that the effects of pulsed RFR at different doses over ten weeks may cause changes in oxidative damage parameters in the spleen tissue of male rats (22). In another study, it was reported that RFR applied at different doses caused degeneration in spleen tissue and loss of megakaryocytes and monocytes (23). Since the spleen tissue/organ is among the tissues sensitive to ionizing radiation, it has been reported that oxidative damage occurs in the spleen tissues when the body is exposed to a dose of 10 Gy (24). Researchers reported that 900 MHz RFR showed higher levels of irreversible oxidative damage in the main lymphoid organs of immature rats (spleen, thymus, bone marrow) compared to mature rats (25). In the present study, it was evaluated whether central venule loss in white pulp, trabecular irregularity, enlargement in sinusoids, hemosiderin accumulation in the spleen tissue of the exposure group differed from the control group in histopathological terms. As a result of the analysis, it was found that the control group and the exposure groups had a significant change in the scoring of trabecular irregularity and sinusoids. No significant difference was found in the extent of p53 staining by immunohistochemistry. As a result of the observations, it was determined that there was a slightly irregular appearance in the trabeculae of the rat spleen. The literature reports that exposure at different doses and durations may cause damage on spleen tissue. In this study, we found similar findings with the literature, and damage was observed in the trabeculae and sinusoids.

It has been determined that 2100 MHz GSM-like RFR applied to rats did not cause histomorphologically significant changes in heart and spleen tissue. It could be explained that this situation is seen due to short-term exposure and level of the RFR. The protection mechanism of these animals against to the RFR could be another reason for these findings. There is a need for new long-term studies.

Conflict of interest

No conflict of interest was declared by the authors.

REFERENCES

1. Wall S, Wang ZM, Kendig T, Dobraca D, Lipsett M. Real-world cell phone radiofrequency electromagnetic field exposures. Environ Res. 2019;171:581-592.
2. Adebayo EA, Adeeyo AO, Ogundiran MA, Olabisi O. Bio-physical effects of radiofrequency electromagnetic radiation (RF-EMR) on blood parameters, spermatozoa, liver, kidney and heart of albino rats. J King Saud Univ Sci. 2019;31(4):813-821.
3. Miller AB, Sears M, Hardell L, Oremus M, Soskolne CL. Risks to health and well-being from radio-frequency radiation emitted by cell phones and other wireless devices. Front Public Health. 2019;7:223.
4. Kostoff RN, Heroux P, Aschner, M, Tsatsakis A. Adverse health effects of 5G mobile networking technology under real-life conditions. Toxicol Lett. 2020;323:35-40.
5. Misek J, Veternik M, Tonhajzerova I, Jakusova V, Janousek L, Jakus J. Radiofrequency electromagnetic field affects heart rate variability in rabbits. Physiol Res. 2020;69:(4):633-43.
6. Magiera A, Solecka J. Mobile telephony and its effects on human health. Rocz Panstw Zakl Hig. 2019;70(3):225-30.
7. Hancı H, Türedi S, Topal Z, Mercantepe T, Bozkurt İ, Kaya H, Ersöz Ş, Ünal B, Odacı E. Can prenatal exposure to a 900 MHz electromagnetic field affect the morphology of the spleen and thymus, and alter biomarkers of oxidative damage in 21-day-old male rats?, Biotech Histochem. 2015;90(7):535-43.
8. Türedi S, Hancı H, Topal Z, Ünal D, Mercantepe T, Bozkurt İ, Kaya H, Odacı E. The effects of prenatal exposure to a 900-MHz electromagnetic field on the 21-day-old male rat heart. Electromagn Biol Med. 2015;34:(4):390-7.
9. CST Studio Suite AG, www.cst.com, CST AG Germany (last accessed December 05th, 2020).
10. Chauhan P, Verma HN, Sisodia R, Kesari KK. Microwave radiation (2.45 GHz)-induced oxidative stress: Whole-body exposure effect on histopathology of Wistar rats. Electromagn Biol Med. 2017;36(1):20-30.
11. Gürses İ, Özeren M, Serin M, Yücel N, Erkal HŞ. Histopathological evaluation of melatonin as a protective agent in heart injury induced by radiation in a rat model. Pathol Res Pract. 2014;210(12):863-71.
12. Yavaş MC. Effect of electromagnetic field originating from high voltage lines on malondialdehyde level. Middle East J Sci. 2019;5(2):120-5.
13. Yavaş MC, Akpolat V, Devecï E, Bïlgîn HM, Kaplan İ, Seker U, Yïldiz İ, Alkïs E, Celïk MS, Akdağ MZ. Determining the effect of an electromagnetic field generated by a high voltage power line on rat spermatogonia cells. Dicle Tıp Dergisi, 2018;45(4):447-61.
14. Alkis ME, Bilgin HM, Akpolat V, Dasdag S, Yegin K, Yavas MC, Akdag MZ. Effect of 900-, 1800-, and 2100-MHz radiofrequency radiation on DNA and oxidative stress in brain. Electromagn Biol Med. 2019;38(1):32-47.
15. Azab AE, Ebrahim SA. Exposure to electromagnetic fields induces pathophysiological changes and oxidative stress in the cardiovascular system. Saudi J Biomed Res. 2017;2(5): 115-21.
16. Elmas, O. Effects of electromagnetic field exposure on the heart: a systematic review. Toxicol Ind Health. 2016;32(1):76-82.
17. Kiray A, Tayefi H, Kiray M, Bagriyanik HA, Pekcetin C, Ergur BU, Ozogul C. The effects of exposure to electromagnetic field on rat myocardium. Toxicol Ind Health. 2013;29(5):418-25.
18. Goraca A, Ciejka E, Piechota A. Effects of extremely low frequency magnetic field on the parameters of oxidative stress in heart. J Physiol Pharmacol. 2010;61(3):333.
19. Kerimoğlu G. Mercantepe T. Erol HS, Turgut A, Kaya H, Çolakoğlu S, Odacı E. Effects of long-term exposure to 900-megahertz electromagnetic field on heart morphology and biochemistry of male adolescent rats. Biotech. Histochem. 2016;91(7):445-54.
20. Kuzay D, Ozer C, Goktas T, Sirav B, Senturk F, Kaplanoglu GT, Seymen M. Effects of 2100 MHz radio frequency radiation on the viscosity of blood and oxidative stress parameters in hypertensive and normal rats. Int J Radiat Res. 2018;16(4):431-42.
21. Keleş Aİ, Sapmaz T, Erol HS, Süt BB, Keleş G, Odaci E, Polat S, Halici MB. The effect of 900-Megahertz electromagnetic field exposure in the first and middle adolescent period on the spleen in male rats: A biochemical and histopathological study. Duzce Medical Journal. 2019;21(3):192-6.
22. Li BL, Li W, Bi JQ, Zhao JG, Qu ZW, Lin C, et al. Effect of long-term pulsed electromagnetic field exposure on hepatic and immunologic functions of rats. Wien Klin Wochenschr. 2015;127(23-24):959-62.
23. Attia AA, Yehia MA. Histological, ultrastructural and immunohistochemical studies of the low frequency electromagnetic field effect on thymus, spleen and liver of Albino Swiss mice. Pak J Biol Sci. 2002;5(9):931-7.
24. Shin HS, Yang WJ, Choi EM. Se-methylselenocysteine modulates antioxidant response of rat spleen to ionizing radiation. Toxicol Environ Health Sci. 2013;5(3):145-54.
25. Aydin B, Akar A. Effects of a 900-MHz electromagnetic field on oxidative stress parameters in rat lymphoid organs, polymorphonuclear leukocytes and plasma. Arch Med Res. 2011;42(4):261-7.
26. Yücel S, Kaplanoğlu GT, Kaplanoğlu İ, Aral BS, Seymen CM. Kronik cep telefonu radyasyonu ve koruma amaçlı uygulanan melatoninin ovaryuma etkisi. Gazi Medical Journal. 2017;28(3):184-90.