

Effects of 900-MHz electromagnetic fields exposure throughout middle/late adolescence on the kidney morphology and biochemistry of the female rat

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Abstract

The effect of the electromagnetic field (EMF) established when cell phones are in use on human health, and particularly the head, has been the subject of major scientific research. Phones are usually carried near the lumbar region when not in use, and the kidneys will also inevitably be affected by such fields. We investigated the effects on the kidneys of female rats exposed to a continuous 900-megahertz (MHz) EMF for 1 h daily in mid-late adolescence. Control, sham, and EMF groups were established. The EMF was applied to the application group rats daily on postnatal days 35–59. A pseudo-megahertz effect was applied to sham group rats. All animals were euthanized on postnatal day 60. Right kidney tissues were subjected to routine procedures. Malondialdehyde, total antioxidant status, and total oxidant status (TOS) were investigated in left kidneys, and the oxidative stress index (OSI) was also calculated from these. Histopathological analysis revealed no pathology in either the control or sham groups. However, findings including hemorrhage in glomerulus, vacuolization and irregularity in the proximal and distal tubular epithelium, diffuse glomerular degeneration and edema, occasional degeneration in Bowman capsules, hemorrhage in the medullary region, disturbed nucleus location and morphology, and tubular edema in the cortex were observed in the EMF groups. TOS and OSI values were lower in the EMF group (9.4316 ± 1.0211 and 0.8461 ± 0.0826 , respectively) and the sham group (8.2171 ± 0.6437 and 0.7358 ± 0.0545 , respectively) than in the control group (11.1522 ± 1.3389 and 1.0085 ± 0.1174 , respectively) ($p < 0.05$). In conclusion, exposure to a continuous 900-MHz EMF for 1 h daily during middle and late adolescence may cause various changes in the female rat kidney at postnatal day 60.

Keywords

Electromagnetic field, kidney, cell phone, oxidative stress, female rat, adolescence

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Introduction

The effects of the electromagnetic field (EMF) emitted by numerous devices and systems, such as cell phones, computers, and televisions, on human health have recently become the subject of major scientific research. The fact that cell phones are widely employed for other than their original purpose and that they are now also used by children has significantly increased exposure to the effect of EMF. The effect of exposure to EMF during adolescence on tissues, organs, and systems that are not yet fully developed compared to those in adults can have very severe consequences. This is of particular concern because of possible compromise of the normal morphological development of tissues, organs, and systems by exposure to any intrinsic or extrinsic agent during this period (Davis et al., 2013; RNCNIRP, 2011).

Studies have largely concentrated on the effects of EMF emitted during cell phone use on the head and neighboring organs (İkinci et al., 2015; Kerimoglu et al., 2016; Odacı et al., 2008; Sahin et al., 2015). Since cell phones are frequently carried close to the lower back when not in use (in handbags, in trouser pockets or attached to the waist), the kidneys will also inevitably be affected by EMF. This is partly because cell phones constantly update their location when in standby mode. Greater EMF is also emitted when phones first ring. The kidneys are therefore significantly exposed to EMF (Kerimoglu et al., 2018; Odacı et al., 2015). The effect of EMF on the kidneys during childhood and adolescence is therefore a subject requiring investigation.

Sepehrimanesh et al. (2014a) reported histopathological findings in the kidney tissues of male rats exposed to EMF in adulthood. They also stated that these findings were not specific to EMF. However, Türedi et al. (2017) reported that EMF exposure in adolescence caused pathological changes in the kidney in male rats. Cell phone use is more common among females than males (Freier, 2016). Cell phone use is also relatively greater in adolescence compared to other ages (Freier, 2016). Adolescence and female gender were therefore selected in our study. Although cell phones are widely used in childhood and adolescence (Hancı et al., 2013), the effects of exposure to EMF at that time have not been sufficiently investigated. We encountered no previous studies investigating the effects on rat kidney tissue of 900-megahertz (MHz) EMF applied in middle and late adolescence. Because of the widespread use of the GSM 900

system in mobile phone communications in Europe, we elected to use 900-MHz EMF in this study. Histological and biochemical methods were used to investigate the effects on female rat kidney tissue of continuous 900-MHz EMF applied for 1 h daily in mid-late adolescence.

Materials and methods

Study design, ethical procedures, and groups

The study commenced following receipt of approval from the Karadeniz Technical University (KTU) Animal Experiments Local Ethical Committee (Protocol No. 2016/44 dated 27/09/2016). All procedures were consistent with the principles of the *Guide for the Care and Use of Laboratory Animals* published by the US National Institutes of Health. Twenty-four female Sprague Dawley rats aged 34 days were obtained from the KTU Experimental Animals Surgical Research and Application Center (KTUESRAC). These were kept in a 12 h light:12 h dark cycle with no dietary restrictions. Tap water was provided for drinking, together with standard rat chow (Bayramoğlu Yem ve Un Sanayi Tic. A.Ş., Erzurum, Turkey). Temperature was set at $22 \pm 2^\circ\text{C}$ and humidity at $50 \pm 5\%$. Rats were housed in type I rat cages throughout the study. All experimental procedures, and rat maintenance and sacrifice took place in the KTUESRAC. This obviated any problems associated with environmental stress and adaptation. Rats were randomly assigned into control (CGr), sham (SGr), or EMF (EMFGr) groups, each consisting of eight animals.

Experimental protocol

An apparatus subsequently described as the sham/EMF application system was used to establish sham and EMF effects in this study. This system was identical to that used in previous studies by our team (Hancı et al. 2013; Odacı and Özyılmaz, 2015). This principally consisted of an oscillator (1218-BV, Lockable Oscillator, 900–2000 MHz, General Radio Company, Concord, Massachusetts, USA, Serial No. 1483), a continuous fixed power source (1267-B Regulated Power Supply, General Radio Company Serial No. 903), and a sham/EMF application cage ($40.5 \times 31.5 \times 40.5 \text{ cm}^3$). An oscillator capable of adjustment to an output power of approximately 300 mW and a frequency of 900 MHz capable of producing a high-speed frequency was used to

establish a 900-MHz EMF effect. In order to transfer the EMF produced inside the oscillator to the EMF cage, the oscillator outlet was attached by a cable to a half-wave dipole antenna, 15 cm long and 1 mm in diameter, made from a copper rod. The antenna was attached to a wooden rod inserted 11 cm from the top and between the right and left sides of the EMF cage. A 900-MHz EMF effect was thus produced inside the sham/EMF application cage. In order to meet the oscillator's continuous energy needs, a continuous fixed power source was attached to the city electrical grid.

The establishment of sham and EMF effects

Sham group rats were placed inside the sham/EMF application cage capable of producing EMF for 1 h every day, between 09:00 and 10:00 a.m., from postnatal days 35 to 59 inclusive, representing middle and late adolescence in rats (for a total of 25 days) (Tirelli et al., 2013). However, they were not exposed to the effect of EMF during this time. EMFGr rats were placed inside the sham/EMF application cage for 1 h every day, between 10:00 and 11:00 a.m., from postnatal days 35 to 59 inclusive (also for a total of 25 days). During this time, these animals were exposed to the effect of a 900-MHz EMF. CGr rats were not subjected to any procedures.

The intensity of the electric field during application of EMF to EMFGr was determined using a broadband electric field intensity measuring device operating at a range of 100 kHz–2.5 GHz (C.A 43 Isotropic Electrical Field Intensity Meter, Chauvin Arnoux Group, Paris, France). For this purpose, EMF measurements were taken each day during EMF application from nine separate points on the floor and top of the sham/EMF application cage with EMFGr rats inside it. Electric field intensity, power density, and specific absorption rate (SAR) values were calculated on the basis of these measurements. Whole-body SAR values were calculated using a RadHaz SAR Equivalency Calculator (Version 1.0, © 2000 Richard Tell Associates, Inc., Colville, Washington, USA).

Histological procedures

At the end of the experimental period (postnatal day 60), rats were anesthetized and killed by exsanguination (Ketalar® 50 mg/kg, Eczacıbaşı Co., Istanbul, Turkey) and an abdominal midline incision was made with a scalpel, and the right and left kidneys were removed. The surrounding tissue was removed from

both kidneys, which were then weighed. The left kidneys were stored in Eppendorf tubes at -80°C for biochemical analyses, while the right kidneys were fixed in 10% formaldehyde for histological analyses. After being kept in 10% formaldehyde for 48 h, right kidney tissues were subjected to routine histological tissue procedures, embedded in paraffin blocks, and cut into 5 μm sections using a microtome. They were then embedded in paraffin blocks. Sections 5 μm in thickness were taken from the paraffin blocks using a microtome (Leica RM 2255, Leica Instruments, Nussloch, Germany) and then stained with hematoxylin and eosin (H&E) (Bancroft and Cook, 1994). Histopathological evaluations and photographing of the H&E staining sections were carried out using a light microscope (Olympus, BX51, Tokyo, Japan) equipped with a digital camera (DP 71, Olympus).

TUNEL staining and apoptosis evaluation

The terminal deoxynucleotidyl transferase deoxyuridine triphosphate nick end-labeling assay (TUNEL) technique was employed for the assessment of apoptosis in kidney tissues. For TUNEL staining, the paraffin blocks were cut into 5- μm thick serial sections using a microtome (Leica RM 2255, Leica Instruments). They were then exposed to routine deparaffinization procedures and stained using the TUNEL method with a cell death detection kit in accordance with the manufacturer's instructions (In Situ Cell Death Detection Kit POD, catalog number: 11684817910, Roche®, Mannheim, Germany) (Türedi et al., 2016).

Apoptosis was evaluated on TUNEL-stained slides using a light microscope (Olympus, BX51) at a magnification of $400\times$. Numbers of TUNEL (+) cells were observed in renal tubular epithelial cells. Apoptosis was defined as the presence of brown nuclei. One hundred renal tubular epithelial cells were counted in five randomly selected areas in one section for each rat at a magnification of $400\times$, and the findings were recorded. After counting, the apoptotic index (AI) was calculated using the formula $\text{AI} = \text{apoptotic renal tubular epithelial cell nuclei number} / \text{total renal tubular epithelial cell nuclei number counted} \times 100$ (Odacı and Özyılmaz, 2015; Türedi et al., 2016).

Biochemical analyses

Several biochemical parameters in kidney tissue were investigated in order to determine whether renal tissue was affected by EMF. Malondialdehyde (MDA), total antioxidant status (TAS), total oxidant status (TOS),

and oxidative stress index (OSI) values were calculated as markers of oxidative stress.

Determination of tissue MDA levels

MDA measurement was performed by modifying the method described by Mihara and Uchiyama (1978). This is based on measuring the color of the molecule formed by MDA with thiobarbituric acid (TBA) in an acidic environment at an absorbance of 532 nm. Tissue homogenization buffer, 1% H₃PO₄ solution, TBA solution, and standard solutions used in tissue MDA measurement were first prepared. Following preparation of the solutions, specimens of approximately 50 mg each were taken from each tissue. These were then homogenized in 2 mL phosphate buffer (PBS, pH = 7.4) at 9500 rpm (4 × 10 s, 40°C) in an Ultra-Turrax homogenizer (model T25, Jane and Kunkel, Germany). Homogenates were centrifuged for 10 min at 3000xg (Eppendorf 5810, Hamburg, Germany). Supernatants obtained after centrifugation were diluted in PBS at a ratio of 1:10, and MDA levels were measured. During measurement, 200 µL specimens were taken from the resulting supernatant and placed into 96-well plates. Absorbances at a 532 nm wavelength were then read on a microplate reader spectrophotometer (Versamax, Molecular Devices, California, USA). A standard MDA chart was produced by plotting the absorbance results obtained against concentrations. Tissue MDA levels were calculated as nmol MDA/gram wet tissue using this chart.

TOS and TAS determination

TOS levels in tissue specimens were determined using a colorimetric kit (Rel Assay Diagnostics, Cat No. RL0024, Gaziantep, Turkey) as recommended by the manufacturer. TOS analysis is based on the ability of different types of oxidant to oxidize Fe⁺² to Fe⁺³. The resulting Fe⁺³ produces a colored complex with chromogen. This is then measured spectrophotometrically at 530 nm. The data obtained were compared to the standard, and total oxidant capacity in a specimen was determined as µmol H₂O₂Equivalent (Eq)/L. TAS levels in tissue specimens were determined using a colorimetric kit (Rel Assay Diagnostics, Cat No. RL0017) as recommended by the manufacturer. The TAS assay is based on antioxidants in serum reducing the green–blue 2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS) reactive to a colorless form. Changes in absorbance are measured spectrophotometrically at 660 nm. The data obtained are compared to the standard, and the TAS is expressed as µmol trolox Eq/L.

Oxidative stress index

The ratio of TOS to TAS was defined as the OSI. This was calculated according to the following formula (Yulug et al., 2014)

$$\text{OSI} = \frac{\text{TOS } (\mu\text{mol H}_2\text{O}_2 \text{ equivalent/L})}{\text{TAS } (\mu\text{mol trolox equivalent/L})} \times 100$$

Statistical analysis

Statistical analysis was performed using SPSS (Statistical Package for the Social Sciences version 20.0, SSPS Inc., Chicago, IL, USA) software. All numerical data were expressed as mean ± SD. One-Sample Kolmogorov Smirnov test was used to test the normality of distribution. Variance analysis was performed. The Student-Newman-Keuls test was performed post hoc. Those variables exhibiting normal distribution were subjected to analysis of variance using the Student–Newman–Keuls test. P-values <0.05 were regarded as statistically significant.

Results

Kidney weight findings

No statistically significant difference was determined among the groups in terms of right ($p > 0.05$) or left kidney weights ($p > 0.05$). Mean right kidney weights were 0.98 ± 0 g for CGr, 0.98 ± 0 g for SGr, and 0.80 ± 0 g for EMFGr, while mean left kidney weights were 0.91 ± 0 g for CGr, 0.86 ± 0 g for SGr, and 0.80 ± 0 g for EMFGr.

Histopathological analysis findings

Histopathological examination under light microscope of kidney tissue sections stained with H&E revealed a normal morphological structure in the cortex, Bowman capsules, and medullary regions from the CGr and SGr. However, findings such as hemorrhage in glomerulus, vacuolization and irregularity in the proximal and distal tubular epithelium, diffuse glomerular degeneration and edema, occasional degeneration in Bowman capsules, hemorrhage in the medullary region, impairments in nucleus location and morphology, and tubular edema in the cortex were observed in H&E-stained EMFGr sections. Collecting tubules in the medullary region and diffuse hemorrhage between the limbs of the loop of Henle were also prominent features in H&E-stained sections from EMFGr (Figure 1).

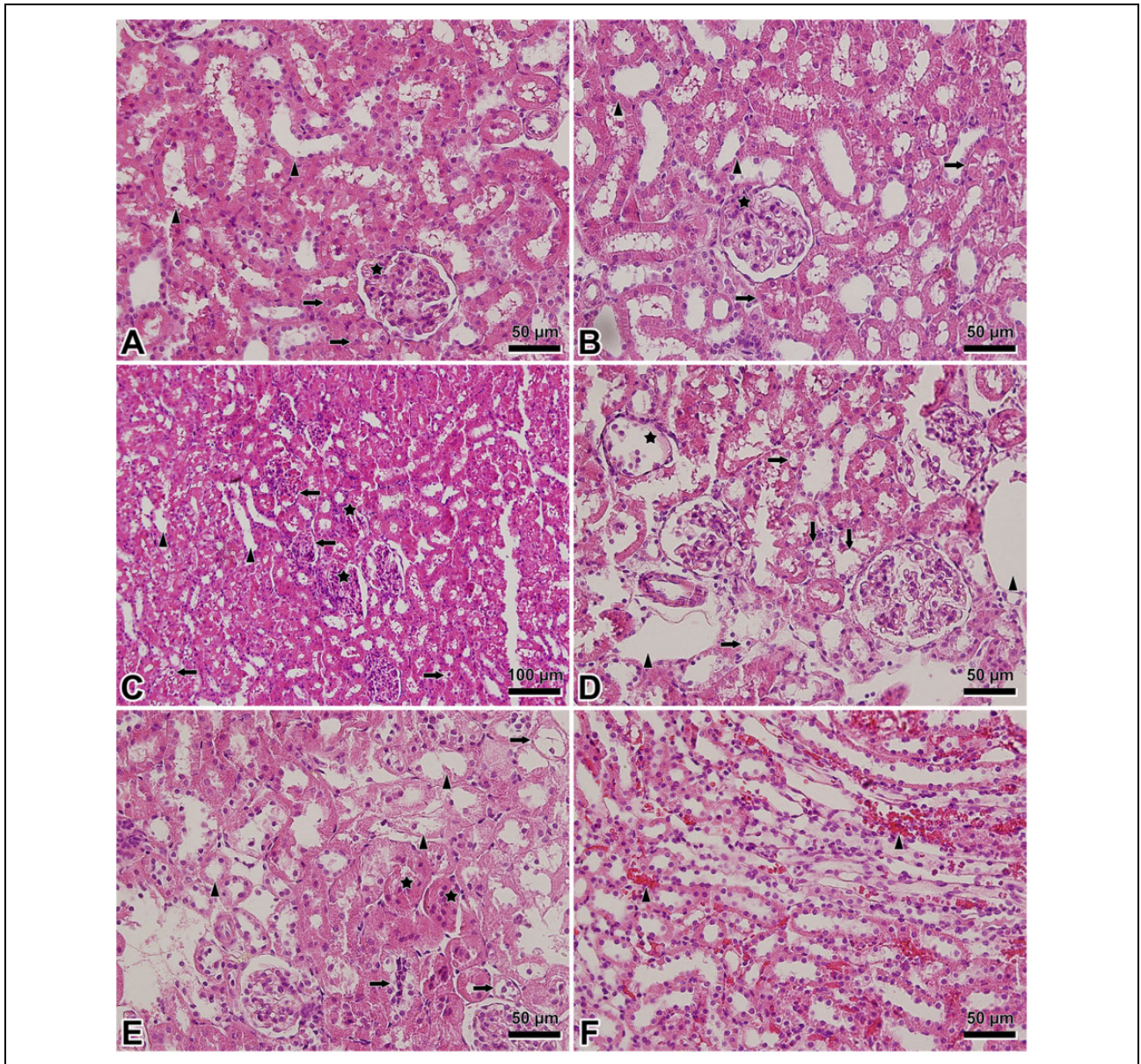


Figure 1. Light microscopic micrographs of rat kidney sections stained with hematoxylin and eosin from control (a), sham (b), and EMF group (c to f) rats at different magnifications. (a) Renal glomerulus (star), proximal tubule (right arrow), and distal tubule (arrow head) with a normal histological structure in histological sections from the control group. (b) Renal glomerulus (star), proximal tubule (right arrow), and distal tubule (arrow head) with a normal histological structure in histological sections from the sham group. (c) Atrophic glomeruli (star), nerve loss (left arrow) between the parietal and visceral layers in the Bowman's capsule of the glomerulus, vacuolization in proximal and distal tubular epithelial cells (right arrow), and tubular distension (arrow head) in histological sections from the EMF group. (d) Atrophic glomeruli (star), vacuolization in proximal and distal tubular epithelial cells (right arrow), tubular distension (arrow head), and tubular degeneration (bottom arrow). (e) Disorganization in proximal and distal tubular epithelial cells (star), tubular epithelial cell loss (arrow head), and tubules tending toward atrophy (right arrow). (f) Collecting tubules in the medullary region and diffuse hemorrhage between the limbs of Henle's loop (arrow head). (H&E, panels a, b, d to f $\times 400$, c $\times 200$).

TUNEL assay and apoptosis evaluation results

Apoptotic characteristics were further confirmed by investigation of TUNEL-stained sections under light microscopy at a magnification of $400\times$. Low levels of

TUNEL (+) cells were observed in TUNEL-stained sections from the control and sham groups, while large numbers of TUNEL (+) cells were visible in TUNEL-stained kidney tissue sections from EMFGr

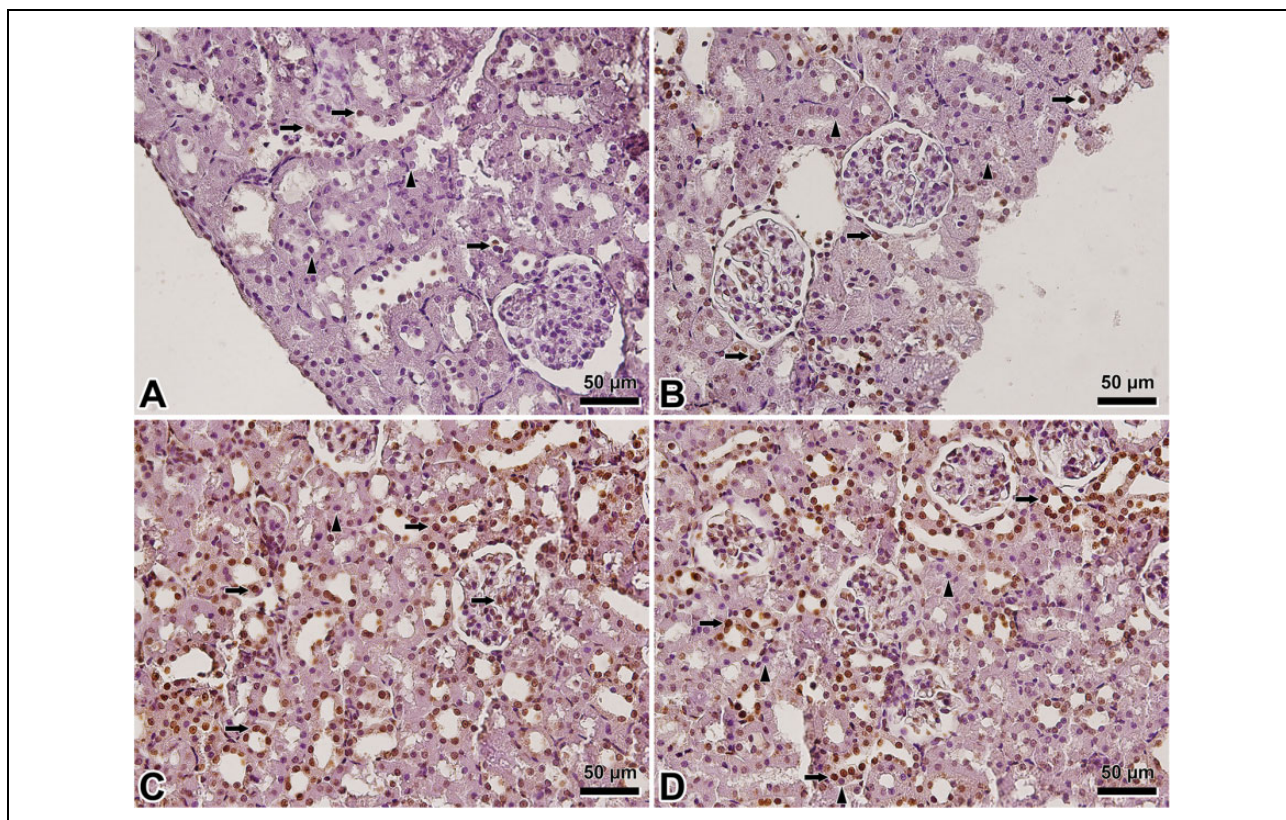


Figure 2. TUNEL-stained rat kidney micrographs from control (a), sham (b) and EMF (c and d) group rats. Very low numbers of TUNEL (+) (arrows) and large numbers of normal cells (arrow head) can be seen in the control (a) and sham (b) groups, while abundant TUNEL (+) (arrow) cells and low numbers of normal cells (arrow head) appear in the EMF group (c and d) sections (TUNEL, a to d $\times 400$). TUNEL: terminal deoxynucleotidyl transferase deoxyuridine triphosphate nick end-labeling assay.

(Figure 2). AI values were calculated based on the intensity of TUNEL (+) cells in the kidney tissue. The AI in kidney tissue increased significantly in EMFGr compared to CGr and SGr ($p < 0.001$; Table 1).

Biochemical analyses results

Biochemical results indicated no statistical significant differences in tissue MDA and TAS levels between the groups ($p > 0.05$). However, lower TOS and OSI values were observed in EMFGr and SGr compared to CGr ($p < 0.05$; Table 1).

EMF measurement results

The electric field intensity threshold value determined for a single device in GSM 900 base station systems is 10.23 V/m (average power density = 0.28 W/m^2) (ICNIRP, 1998; TÜBİTAK-BİLTEN, 2001). At the beginning and end of EMF application, electric field intensity was measured from nine separate points in

system in which EMFGr was exposed to EMF effect. On the basis of EMF measurements taken on a daily basis throughout the study, mean EMF values inside the cage were $9.5 \pm 0.02 \text{ V/m}$, the average power density was 0.239 W/m^2 , whole-body SAR value was 0.012 W/kg (Table 2). SAR is an approximate and crude value involving several assumptions.

Discussion

Limited numbers of studies have investigated the effects of EMF on the kidney in different periods. However, no studies have to date investigated the effects of 900-MHz EMF on the female rat kidney during the various stages of adolescence. Excessive mobile phone use at this time and exposure to EMF thus lead to oxidative stress and increased tissue damage, both by increasing ROS and by suppressing antioxidant defense system mechanisms (Kaplan et al., 2016). The investigation of the effect of a 900-MHz EMF on the kidney, a vital organ, is therefore of

Table 1. Biochemical data and apoptotic index values for control, sham, and EMF group rat kidney tissues.^a

Parameters	CGr	SGr	EMFGr
MDA (nmol/mg of tissue)	535.5 ± 98.6769	733.012 ± 266.1873	665.275 ± 310.3016
TOS (μmol H ₂ O ₂ eq/L)	11.1522 ± 1.3389	8.2171 ± 0.6437 ^b	9.4316 ± 1.0211 ^b
TAS (mmol trolox eq/L)	1.1056 ± 0.0285	1.1167 ± 0.2838	1.114 ± 0.0223
OSI	1.0085 ± 0.1174	0.7358 ± 0.0545 ^b	0.8461 ± 0.0826 ^b
AI (%)	13.2 ± 5.2318	23.2 ± 7.6638	39.28 ± 10.0394 ^c

EMF: electromagnetic field; CGr: control group; SGr: sham group; EMFGr: EMF group; MDA: malondialdehyde; TOS: total oxidant status; TAS: total antioxidant status; OSI: oxidative stress index; AI: apoptotic index.

^aData are expressed as mean ± SD; $p < 0.05$; $n = 8$ in each group.

^bTOS and OSI levels in EMFGr and SGr decreased compared to CGr ($p < 0.05$).

^cEMFGr values increased significantly compared to CGr and SGr ($p < 0.001$ and $p < 0.001$, respectively).

Table 2. Mean EMF intensity measurement (MEFI), power density (PD), and specific absorption rate (SAR) values depending on EMF application time and measurements from nine separate points on the cage floor.^a

EMF application time	Cage floor measurement surface	MEFI (V/m)	PD (W/m ²)	SAR (W/kg)
Beginning of application	Exterior surface of the cage floor	8.12 ± 1.94	0.175	0.0087
	Interior surface of the cage floor	9.51 ± 3.90	0.24	0.012
End of application	Exterior surface of the cage floor	8.44 ± 3.27	0.189	0.0094
	Interior surface of the cage floor	9.48 ± 3.66	0.238	0.0118
Mean values at the beginning and end of application	Exterior surface of the cage floor	8.28 ± 0.22	0.182	0.009
	Interior surface of the cage floor	9.5 ± 0.02	0.239	0.012

^aData are presented as mean ± SD.

considerable importance. The present study was planned for that purpose.

Previous studies have investigated the effect of EMF on rat kidney tissue at different stages. For example, in a study involving adult rats, Koca et al. (2013) reported glomerular damage, dilatation in Bowman's capsule, separation between tubules, and perivascular edema in the kidney tissue of an EMF group exposed to mobile phones. They also reported irregular thickening in the basal membrane, irregularity in the capillary endothelium, and interrupted connections between tubular cells at electron microscopic analysis. Ragy (2015) investigated whether oxidative stress occurred in the brain, liver, and kidney of adult Albino rats exposed to the effect of 900-MHz EMF. They reported statistically significant increases in tissue MDA and tissue TAS values and in urea and creatinine levels in all three organs in the EMF group compared to other groups. The authors suggested that 900-MHz EMF may exacerbate oxidative stress and impair kidney functions.

Devrim et al. (2008) reported that 900-MHz EMF caused oxidative stress in the kidneys of female rats. Odacı et al. (2015) reported degenerative changes in the renal tubular epithelium and small cystic structures in tubules and larger cystic structures in

corticomedullary or medullary regions at the microscopic level in male rats exposed to 900-MHz EMF in the prenatal period. At the electron microscope level, they observed losses in peritubular capillary and peritubular epithelial cells in the EMF group. At biochemical analysis, MDA levels increased while superoxide dismutase (SOD) and catalase (CAT) levels decreased in the EMF group. Odacı et al. (2015) concluded that 900-MHz EMF applied in the prenatal period may cause oxidative stress, a decrease in antioxidant enzyme levels and pathological changes in the renal tissue of 21-day-old male rats. Bedir et al. (2015) also investigated on postnatal day 60 the kidneys of female rat pups exposed to EMF established *via* mobile phones in the prenatal period. They reported mild dilatation in Bowman's capsule, degeneration in the distal tubular epithelium, vacuolization, deformation and dilatation in glomerulus, an increase in connective tissue, and increased vacuolar degeneration and apoptosis in the kidneys of EMFGr rats. Kuybulu et al. (2016) reported that chronic exposure to 2.45 GHz wireless devices before and after birth may cause chronic kidney injury and recommended that exposure to EMF be avoided, particularly during pregnancy and early childhood.

Although the rats used in other studies were at different stages of development, the morphological findings observed in rats exposed to EMF in those studies are similar to our own results. The most important difference between this study and others in the literature is that the rats exposed to the effect of EMF were in different stages. We investigated the effects on the kidneys of female rats exposed to continuous 900-MHz EMF for 1 h daily in mid-late adolescence. This stage of development was selected since cell phones are now widely used at that age among humans (Davis et al., 2013; RNCNIRP, 2011).

Oxidative stress can initiate apoptotic or necrotic cell death (Consales et al., 2012; Goraca et al., 2010). MDA, one of the end products of lipid peroxidation, is a significant marker of oxidative stress (Jackson, 1999). There is therefore a very strong probability of oxidative stress occurring in organs such as the kidney exposed to EMF emitted by cell phones, and therefore of changes in renal tissue MDA levels and in OSI values resulting from alterations in TAS and TOS. However, the oxidative stress markers in this study do not support the idea that the effect of 900-MHz EMF causes oxidative stress, since MDA values in EMFGr did not differ from those of the other groups. However, other studies have shown that EMF does cause an increase in oxidative stress markers (Emre et al., 2011; Yurekli et al., 2006). Antioxidant stress enzyme levels have also been investigated to determine whether EMF results in oxidative stress. While significant variations have been observed in the levels of some such enzymes, none have been determined in others. For example, Sepehrimanesh et al. (2016) examined glutathione peroxidase, glutathione reductase, and superoxide levels while investigating the effects of EMF on oxidative stress, but determined a significant increase only in glutathione peroxidase levels, with no significant difference being observed in other antioxidant enzymes. In a different study, they exposed adult male rats to 1-, 2-, and 4-h EMF for 30 days. They then investigated protein profiles in testis tissues and reproductive hormone levels in blood. Marked changes were observed in animals exposed to 4-h EMF in particular, and the authors reported that long-term exposure may cause greater changes (Sepehrimanesh et al. 2014b, 2014c, 2017). However, another study reported that exposure to 1-h EMF for 30 days caused pathological changes in testis tissues in adult rats (Odacı and Özyılmaz, 2015). In our study, rats were exposed to EMF in mid and late adolescence, and application for 1 h a day resulted in

oxidative stress and histopathological changes in kidney tissue. We think that these differences may be due to rats being exposed to EMF in different periods, the type and intensity of EMF, or rat gender differences. Different results being reported in similar studies may derive from all tissues examined having different biochemical, anatomical, functional, and physical properties (Devrim et al., 2008). In addition, variations in results from similar EMF studies may also be due to the type, dimension, and length of exposure to EMF and the types of animals used as experimental subjects (Seyhan and Güler, 2006). Oxidative stress occurs at times of imbalance between oxidative and antioxidant agents and/or insufficient antioxidant defense mechanisms (Shah and Channon, 2004). The 900-MHz EMF used in this study may have compromised that balance. Additionally, TAS involves several antioxidant elements. Oxidants need to increase considerably in order for TAS to decrease. The oxidative stress in our study may not have been at a sufficient level to reduce TAS, while antioxidant systems may have compensated for oxidative stress through rapid activity and may even have lowered TOS and OSI. TOS and OSI values in EMFGr may therefore have decreased compared to those in CGr. These factors may account for the differences observed between our biochemical data and those of previous researchers. Although groups of eight animals each have been used in previous studies, the fact that the number of animals in the groups in our study was limited to eight nevertheless represents one of its limitations (Kerimoglu et al., 2018; Odacı and Özyılmaz, 2015). Nonetheless, AI in kidney tissue in our study increased significantly in EMFGr compared to CGr and SGr. The biochemical data from our study suggest that although exposure to EMF did not cause oxidative stress in kidney tissue, it did lead to an increase in apoptosis.

In conclusion, on the basis of our study findings, we conclude that exposure to the effect of a continuous 900-MHz EMF for 1 h a day during mid-late adolescence may cause histopathological changes and increased apoptosis in kidney tissue on day 60. However, we think that further studies are needed using different methods in order to reveal whether these pathological changes are reversible or permanent.

Authors' note

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Declaration of Conflicting Interests

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