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The effect of 4.5 G (LTE Advanced-Pro network) mobile phone radiation on the optic nerve

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ABSTRACT

Purpose: Rapid development in mobile phone technologies increase the average mobile phone usage duration. This increase also triggers exposure to radiofrequency radiation (RF), which is a risk factor for the health. In this study, it was aimed to investigate the effect of mobile phone working with LTE-Advanced Pro (4.5 G) mobile network on the optic nerve, which is responsible for the transmission of visual information.

Material and methods: Thirty-two rats divided into two groups as control (no RF, sham exposure) and experimental (RF exposure using a mobile phone with LTE-Advanced Pro network; 2 hours/day, 6 weeks). The visual evoked potential (VEP) was recorded and determined amplitudes and latencies of VEP waves. Optic nerve malondialdehyde level, catalase and superoxide dismutase activities were determined. Furthermore, ultrastructural and morphometric changes of optic nerve were evaluated.

Results: In VEP recordings, the mean VEP amplitudes of experimental group were significantly lower than control group. In ultrastructural evaluation, myelinated nerve fibres and glial cells were observed in normal histologic appearance both in sham and experimental group. However, by performing morphometric analysis, in the experimental group, axonal diameter and myelin thickness were shown to be lower and the G-ratio was higher than in the sham group. In the experimental group, malondialdehyde level was significantly higher and superoxide dismutase and catalase activities were significantly lower than sham group. There was a high correlation between VEP wave amplitudes and oxidative stress markers.

Conclusion: Findings obtained in this study support optic nerve damage. These results point out an important risk that may decrease the quality of life.

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Optic nerve; mobile phone; LTE-Advanced Pro; VEP; oxidative stress; g-ratio

Introduction

Worldwide mobile phone usage has increased rapidly in recent years. Today, the number of individual mobile phone users in the world is around 5.117 billion. In the last 12 months, the total number of individual mobile users in the world has increased by 100 million[1]. The reason for this dramatic growth is the development of the five different generation (1 G to 5 G) in mobile phone since the early 1980s. Although the 1 G mobile wireless network can only be used for analogue voice calls, the 4 G and 5 G has focussed on unlimited wireless and very fast data transmission in the world and this has been largely achieved[2]. These features allow the use of 4 G and 5 G in many areas in life such as voice calls, sending messages, e-mail, web, TV, program downloading and others[2]. Today, the most commonly used mobile technology all over the world is called as LTE-Advanced Pro (4.5 G) which has some improved features than its predecessor LTE (4 G) technology and is accepted as a milestone for the next generation 5 G mobile technology[2]. There are many factors that make 4.5 G widespread, such as its almost 50 times faster data transfer speed and wider bandwidth with respect to 4 G, enhancement of energy efficiency and spectral efficiency, flexible networking, etc[3].

Mobile phones working with LTE-Advanced Pro mobile technology use radiofrequency (RF) fields with a frequency band of 800–2600 MHz for their services. RF fields are classified as a form of non-ionizing electromagnetic radiation and they can be absorbed by tissues[4] The amount of absorbed energy that a mobile phone user is exposed to depend on many factors such as the technology of the phone, the distances between the user and the phone as well as phone base stations, the duration of use, the extent and the type of mobile phone used[4]. The possible harmful effects of RF fields on living organisms investigated by many researchers and they reported negative influence on central nervous system[5–7], peripheral nervous system[8], thyroid gland[9], reproductive system[10–13], auditory system[14], blood[15,16] and

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cardiovascular system[17]. On the other hand, some studies in literature suggest that exposure to RF fields do not have harmful health effects[18–20].

Unlimited usage areas and very fast communication lead to an increase in the daily usage duration of mobile phones. The average usage duration of mobile phones in worldwide is reported as 4 h[21]. Eyes are a particular concern for higher generation mobile phone applications because they are likely to be exposed to a significant amount of RF radiation due to increasing long-term use. Studies investigating RF radiation effects on eyes are mostly concentrated on the lens. Some of these studies reported that RF radiation leads to cataract formation and damage in the lens[22–24], while others reported no effect on the lens[25,26]. Fewer studies are available on RF effects on other tissues of eye. In one of these studies, following exposure to RF radiation, transient changes were observed in the electroretinogram correlated with photoreceptor degeneration[27]. In another study, researchers found out degenerative retinal changes in rabbits exposed to pulsed RF radiation by electron microscopy analysis[28]. To the best of our knowledge, in the literature, there are no studies investigating the effects of radiofrequency radiation on optic nerve. In this study, it is aimed to investigate the effects of LTE-Advanced Pro network working on a mobile phone on the optic nerve via electro-biophysical, histological and biochemical techniques.

Materials and methods

Animals

Ethical approval of this study was taken from Experimental Animals Local Ethics Committee of Mersin University and the study was carried out in accordance with the National Institutes of Health's Guide for the Care and Use of Laboratory Animals. Thirty-two Wistar albino male rats, 200–250 g in weight, were obtained from Mersin University Experimental Animal Centre (Mersin, Turkey). The animals parted randomly into two groups of 16 animals. One of the groups was treated as control (no RF, sham exposure) and the other was treated as experimental (RF exposure originated from a mobile phone with LTE-Advanced Pro network connection) group. All animals were housed under the 12:12 h day-night cycle in polycarbonate cages, ($430 \times 290 \times 201$ mm, 6 rats per cage) at $24 \pm 1.3\,^{\circ}C$ and 55% humidity.

RF exposure system

The RF application system to be used in the experiments is designed by considering the average distances between the eyes of a person looking at the screen of his phone under normal conditions. Considering that this value varies between 25 and 35 cm, a cylindrical structure with a radius of 30 cm and a height of 30 cm was designed and manufactured using Plexiglas material. The top of this structure is covered with a flat cap made of delrin plastic. In the middle of this cap, a space is left to place the mobile phone with the screen facing downward and to enable the mobile phone's screen to be fully visible from the inside of the cylinder. In addition, 17 ventilation holes each having 4 cm diameter were opened on the cover to provide ventilation for the cylinder assembly. By means of these design parameters, considering that the distance between the eyes of a rat in a normal posture position and the ground is around 7–8 cm, the distance between the eyes of the rats in the cylinder and the phone screen is ensured to be between 23 cm and 37 cm, which mimics the corresponding distances between an human eye and a phone screen looking on it at different positions and distances (Figure 1). A galvanized plate was set under the plexiglass chamber to reduce the other static electric and magnetic field effects.

RF exposure was performed for 6 weeks, 2 h a day. A LTE-Advanced Pro compatible mobile phone with body SAR value of 0.54 W/kg was used for this process. In order to both mimic human exposure in a similar situation and to ensure that the LTE-Advanced Pro connection is continuously active, a Skype voice call was initiated between the experiment phone and another phone, and this Skype connection continued for an uninterrupted period of 2 h. During this exposure period, the screen of the phone was closed (the phone is locked) to remove the light effects emitted from the screen on eyes and the voice was muted at both sides of the communication to remove voice and vibration effects.

In order to prevent the rats from getting stuck in the setup, experiment and control groups were divided into two (8 each). The division process in each group was done randomly before the experiment of each day. The rats in the sham group were also taken into the experimental setup as 2 groups of 8 rats and were kept in the experimental environment for 2 h every day only when the mobile phone was switched off, with the other conditions remaining the same.

Dosimetry, calculation of specific absorption rate (SAR)

During the experiment, electric field measurements were made in different parts of the test chamber using PMM 8053 electric field probe. The mean electric field value was utilized to determine the distribution of electric field and to calculate the SAR value. Mean E-field value was 4.67 ± 0.82 V/m in test chamber when the mobile phone was active. Specific absorption rate (SAR) was calculated numerically using finite integration technique via CST Microwave Studio electromagnetic field solver. Firstly, a previously designed smart phone model, which has similar communication interfaces (802.11 a/b/g/n, Bluetooth etc.) and antennas, similar screen type and size, similar cover and similar SAR value, is loaded to the solver and then, radiation simulations were made using the modelling methods defined on the program. A voxel rat model was reconstructed from 2 D computerized tomography scan images and this rat model was used in field simulations for determination of electric field distribution and SAR. Mesh type is selected as hexahedral, and an automatic mesh generator was used for mesh production in order to select the best point between accuracy and simulation time. IEEE/IEC 62704–1 standard was followed for the calculation of peak spatial-average SAR for 10 g of mean mass in the rat voxel model.

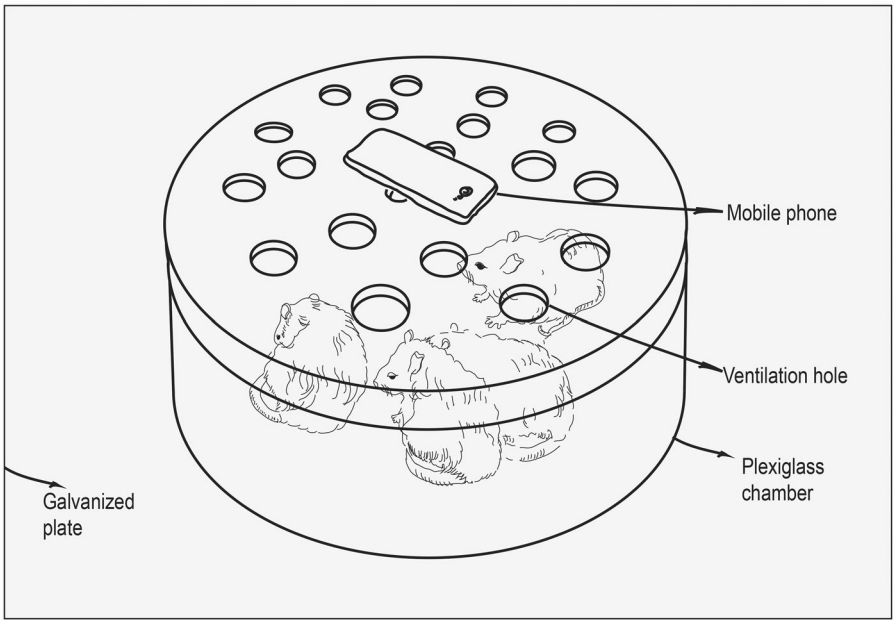


Figure 1. Schematic illustration of exposure system.

Measurement of body surface temperature

An infra-red thermal camera was used for the measurement of body surface temperature before and after exposure both in the control (sham exposure) and experimental (RF exposure) groups. The images were then loaded to computer for further analysis with Smart View 3.5 program.

Visual evoked potential (VEP) recordings

While rats in the experiment and sham groups were under anaesthesia of ketamine (80 mg/kg) and xylazine (8 mg/kg); left, right and bilateral eye visual evoked potentials were recorded against flash stimuli in a dimly illuminated, electrically shielded, sound attenuated room, via the Ag-AgCl disc electrode placed in the occipital region above the visual cortex according to the method described Paxinos et al.[29]. Reference and ground electrodes were placed on the earlobes of the rats (Figure 2). All electrode impedances were kept below 10 kohm. Flash stimuli triggered by a computer program were presented with a LED (light emitting diode) based photo stimulator. The duration of the flash stimuli was 30 ms and the inter stimulus interval (ISI) was 1100 ms. The illumination of the reflecting surface behind the LED was approximately 40 Lux. EEG signals were amplified between 0.1 Hz and 70 Hz, and digitized using 16-bit analog/digital converter (National Instruments, Texas) with a sampling rate of 256 Hz. After elimination of the artefacts, EEG epochs (100 ms pre-stimulus and 400 ms post-stimulus period) were baseline corrected to pre-stimulus 100 ms period and were averaged time-locked to the stimulus onset. Amplitudes and latencies of P2, N2 and P3 potentials, which are shown on the screen of recording PC in Figure 2, and peak-to-peak amplitudes of P2-N2 and N2-P3 components were measured and analysed in averaged VEP responses according to the recommendations of the International Society for Clinical Electrophysiology of Vision[30].

Biochemical analysis

Optic nerve protein content

Lowry method is a biochemical assay for determining proteins in samples[31] (Lowry et al. 1951). After the isolation process, samples of the fresh optic nerves were homogenized with 50 mM phospate buffer (pH 7.4). Then, for 15 min homogenates were centrifuged at 4 °C. Afterwards, a 750 nm spectrophotometer used for measurement of the protein concentration.

Optic nerve malondialdehyte (MDA) level

Yagi method is used for calculation of MDA levels of optic nerve as nmol/mg protein[32]. For the measurement a Carry spectrophotometer at a wavelength of 532 nm (pink colour) was used.

Optic nerve catalase (CAT) activity

CAT activity of optic nerve was measured in supernatants according to the Aebi method[33]. The decomposition of hydrogen peroxide was monitored spectrophotometrically at 240 nm. The difference in absorbance per unit time was used to measure CAT activity and enzyme activity was shown as U/mg protein.

Optic nerve superoxide dismutase (SOD) activity

Tissue SOD activity is based on the principle of measuring superoxide radicals spectrophotometrically at 560 nm and activity was expressed in U/mg protein[34].

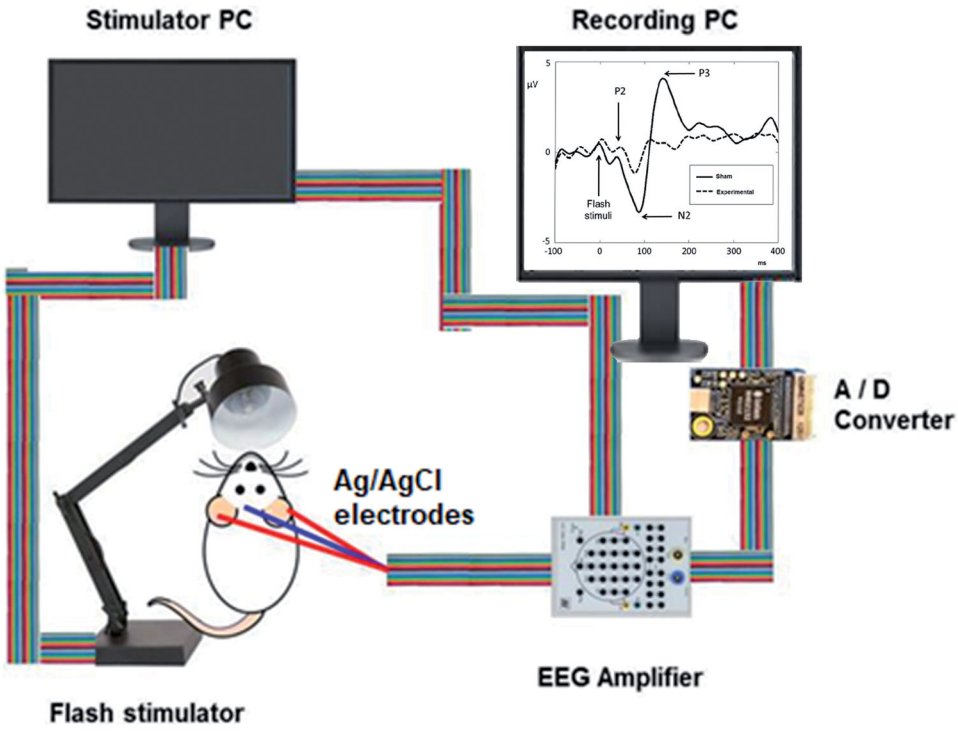


Figure 2. Schematic diagram of VEP recordings. The figure in the recording PC shows a sample of VEP record from experimental (dashed line) and control (straight line) groups in this study.

Histological and morophometric evaluation of optic nerve

After VEP recordings, the animals were sacrificed by overdose ketamine. Following sacrifice, the optic nerves 2.5 mm proximal to the globes were isolated. Optic nerve samples were fixed to 2.5% glutaraldehyde solution for four hours. At the end of this period, the fixed tissues were washed with phosphate buffer. After application of standard electron microscope procedures, tissues were embedded in epoxy resin. From these blocks, 50–70 nm thick sections were taken with ultra-microtome (Leica UCT125, Leica GmbH, Germany), and these ultra-thin sections were contrasted with uranyl acetate and lead citrate solutions. Contrasted sections were examined by transmission electron microscopy (JEOL JEM1011, JEOL Corp., Tokyo, Japan). Later, they were photographed with a digital camera (Mega view III, Olympus GmbH, Germany) attached to the electron microscope.

For morphometric analysis of optic nerve, the myelin sheath thickness and axonal diameter were measured in a hundred fields of each sample section (Figure 3). Axon diameter and myelin sheath thickness were measured according to the method suggested by Yamamato et al.[35]. These measurements were used for calculating G-ratio. The G-ratio of a nerve fibre is expressed as the ratio of axon diameters, itself to with myelin sheath[35–37].

Statistical analysis

The results were statistically analysed using IBM SPSS Statistics version 20.0 (IBM, Istanbul, Turkey). To check normality of variables, Kolmogorov-Smirnov test was used. Statistically comparisons of control and experimental groups were evaluated by using student's *t* test. Data were expressed as mean ± standard deviation (SD). Pearson correlation test was used to determine the correlation between the VEP wave amplitudes and oxidative stress parameters such as MDA level and antioxidant enzyme activities. *p* Values <0.05 were considered statistically significant.

Results

Electric field and SAR distributions

Figure 4(A,B) shows the distribution of electric field and SAR, respectively. As seen, maximum E field was 5.0 V/m (Figure (4A)) and maximum SAR (10 g) was 0.01 W/kg (Figure 4(B)). The SAR value in the area of eyes was about 0.0035 W/kg (Figure 4(B)).

Body surface temperature

Before and after exposure, body surface temperatures were 28.08 ± 0.19 and 28.07 ± 0.26 °C, respectively in the sham group. These values were 28.37 ± 0.29 and 28.39 ± 0.22 °C, respectively for the RF groups. There was no significant difference within sham ($p = 0.275$) and RF ($p = 0.120$) groups before and after exposure. Also, there was no significant differences in surface body temperature between sham and RF exposed groups before ($p = 0.142$) and after ($p = 0.321$) exposure.

VEP analysis

Table 1 shows the amplitude and latency values of P2, N2 and N3 waves for sham and experimental groups. In the experimental group, a significant reduction in the N2, P3, P2-N2 and N2-P3 amplitudes were observed when compared to

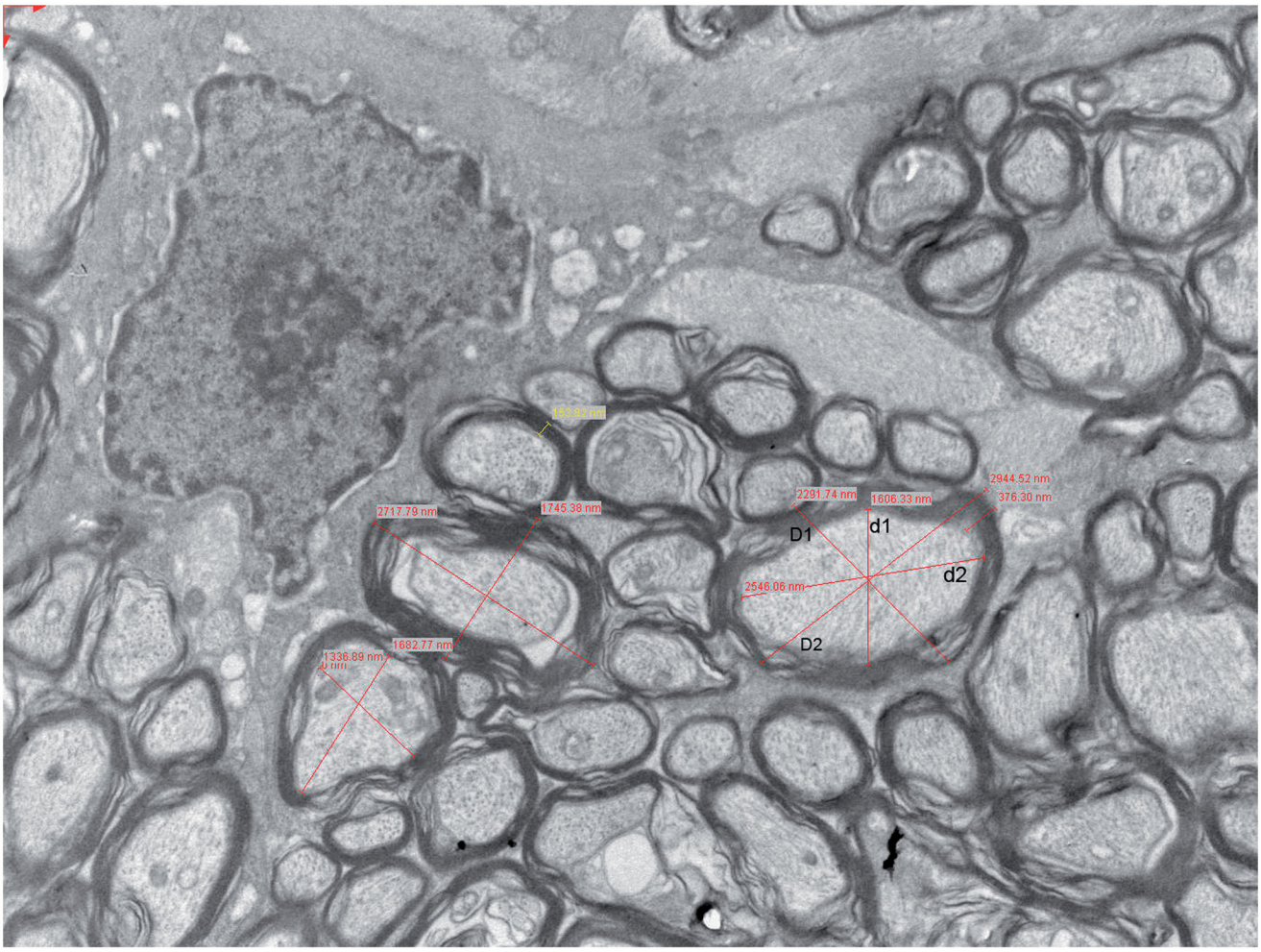


Figure 3. Morphometric analysis of optic nerve with transmission electron microscope. D1: vertical outer diameter, D2:horizontal outer diameter, d1: vertical inner diameter, d2: horizontal inner diameter. The mean nerve fiber diameter=D1+D2/2; the mean axon diameter=d1+d2/2; G-ratio= mean axon diameter/mean nerve fiber diameter.

Table 1. VEP amplitude and latency values in sham and experimental groups.

Variables	Wave	Sham	Experimental
Amplitude (μV)	P2	−3.97 ± 2.09	0.52 ± 0.95
	N2	−3.97 ± 2.09	−1.31 ± 1.28*
	P3	4.36 ± 2.24	0.89 ± 0.92*
	P2-N2	3.92 ± 2.12	1.83 ± 0.81*
	N2-P3	8.33 ± 3.83	2.20 ± 1.35*
Latency (ms)	P2	45.14 ± 7.43	49.87 ± 7.54
	N2	84.57 ± 9.39	80.01 ± 6.23
	P3	140.57 ± 9.13	112.53 ± 4.75

All data were presented as mean ± standard deviation.
*$p < 0.05$ was considered as statistically significant.

sham group. P2 amplitude did not change significantly. In P2 and N2 latencies any significant changes were not observed between groups but in the experimental group, P3 latency shortened (Table 1).

Biochemical analysis

Optic nerve MDA level, SOD and CAT activity for sham and experimental groups were shown in Table 2. MDA level was significantly increased in the experimental group compared to sham group. In the experimental group, mean SOD activity was significantly lower than sham group. Similarly, in the experimental group, CAT activity was significantly lower than sham group.

Table 2. Mean ± SD of MDA level and SOD and CAT activity in sham and experimental groups.

Variable	Sham	Experimental
MDA (nmol/mgprotein)	3.49 ± 1.89	7.62 ± 1.03*
SOD (U/mg protein)	12.37 ± 2.43	5.94 ± 0.46*
CAT (U/mg protein)	24.03 ± 14.21	11.11 ± 1.33*

*Significantly different from sham group ($p < 0.05$).

Histological evaluation

Figure 5 shows the electron microscopic images of sham and experimental groups. As seen, myelinated nerve fibres and glial cells were observed in normal histologic appearance for both groups. On the other hand, in morphometric analysis, the axonal diameter and myelin sheath thickness significantly decreased in RF exposed rats compared with sham-treated rats while the G-ratio increased significantly ($p < 0.05$; Table 3).

Correlation between the VEP wave amplitudes and oxidative stress markers

For the measurement of the correlation between VEP wave amplitudes and oxidative stress, a Pearson correlation analysis was executed across both groups of rats. P2 amplitude

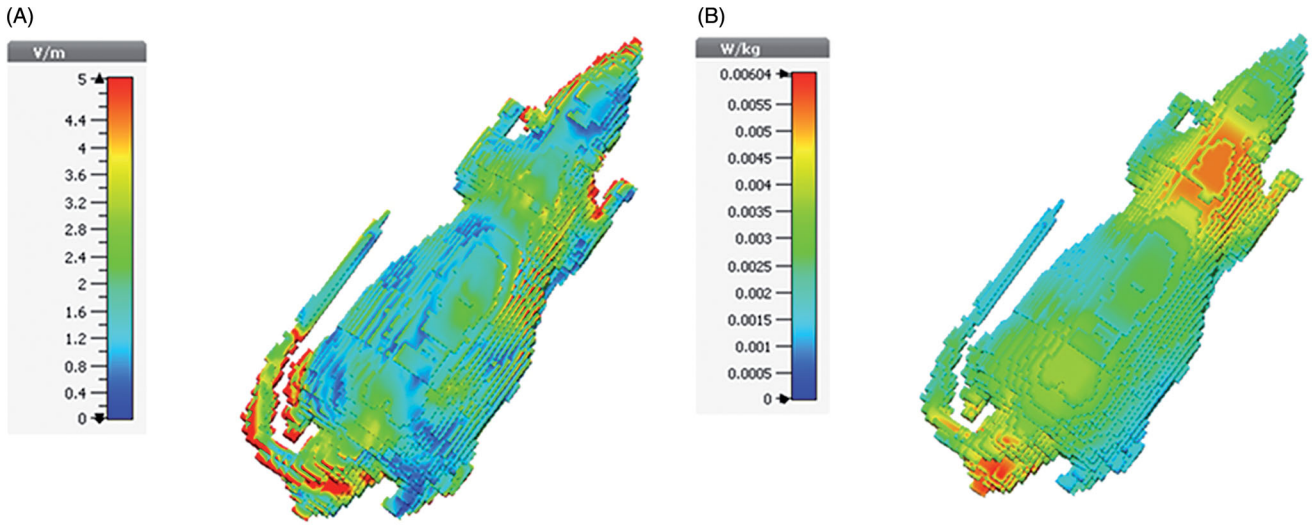


Figure 4. Distribution of electric field (A) and SAR (B) values.

Table 3. Morphometric analysis of optic nerve in sham and experimental groups.

Variable	Sham	Experimental
Axonal diameter (μm)	1.46 ± 0.17	1.31 ± 0.13*
myelin sheath thickness (μm)	0.35 ± 0.07	0.26 ± 0.03*
G-ratio	0.79 ± 0.18	0.82 ± 0.05*

All data were presented as mean ± standard deviation.
*Significantly different from sham group ($p < 0.05$).

Table 4. Pearson's correlation analysis of VEP wave amplitudes and oxidative stress markers (SOD CAT and MDA).

VEP wave amplitudes (μV)	SOD (U/mg protein)	CAT (U/mg protein)	MDA (nmol/mg protein)
P2	0.656*	−0.238	0.720*
N2	−0.805*	−0.366	0.719*
P3	0.619*	0.628*	−0.735*
P2N2	0.729*	0.354	−0.602*
P3N3	0.745*	0.422	−0.727*

*Correlation is significant at the 0.05 level.

and SOD activity was positively correlated with each other. MDA level and P2 amplitude was positively correlated with each other. CAT activity did not correlate with P2 amplitude. N2 amplitude was negatively correlated with the SOD activity and positively correlated with MDA level. N2 amplitude did not correlate with CAT activity. P3 amplitude was positively correlated with SOD and CAT activity and negatively correlated with MDA level. SOD activity and P2N2 amplitude was positively correlated with each other. MDA level was negatively correlated with P2N2 amplitude. P2N2 amplitude did not correlate with CAT activity. SOD activity was positively correlated with P3N3 amplitude. MDA level was negatively correlated with P3N3 amplitude. P3N3 amplitude did not correlate with CAT activity (Table 4).

Discussion

In recent years, everyone, from child to old, has a smartphone, and everyday a long time is passed looking at the screen of this phone. Comfort and efficiency achieved thanks to the high data transfer rate provided by LTE-Advanced Pro technology increase this time day by day. Eyes are the most affected body parts from this condition. In addition to the effects such as strabismus and eye impairment arising from looking at a small screen, it is also important to examine the hidden risks that the RF magnetic field created by the phone will cause on the eye. In this study, the effects of RF emission created by a LTE-Advanced Pro technology phone on the optic nerve were examined in all aspects and the findings were given in the previous section. Briefly it can be said that, for the first time in scientific literature, the findings of the present study indicate that the LTE-Advanced Pro mobile phone radiation causes significant damage by triggering oxidative stress in the optic nerve. LTE-Advanced Pro technology uses a wider RF band between 800 MHz and 2600 MHz and the network system selects the most appropriate band itself according to the user's requirements. It is known that penetration depth of RF increases with decreasing frequency[38]. Since effects of RF radiation were observed on the optic nerve which is behind the eye, it can be said that low frequency bands such as 800 MHz were mostly active during the experiments. Maybe this inference cannot be generalized for all communication purposes, but usage probability of low frequency bands during LTE-Advanced Pro smart phone usage will always keep the damage risk on optic nerve alive.

The VEP is an important electrophysiological test for the analysis of optic nerve and visual pathway damage[39]. VEPs provide a precise indicator of abnormal transmission in the visual path. The abnormalities in amplitude and wave form of VEPs can also be caused by axon loss in the path. There was a significant relationship between optic nerve dysfunction and amplitude change[39]. Therefore, for the investigation of demyelinating disease, optic neuritis and other optic neuropathies, VEPs are widely used[40,41]. In the present study, VEP was recorded from sham exposed and LTE-Advanced Pro mobile phone radiation exposed rats and was evaluated using P2, N2, P3, P2-N2 and N2-P3 amplitudes and P2, N2 and P3 latencies measured from these recordings. The findings of the current study show that exposure to LTE-Advanced Pro RF causes amplitude changes rather than

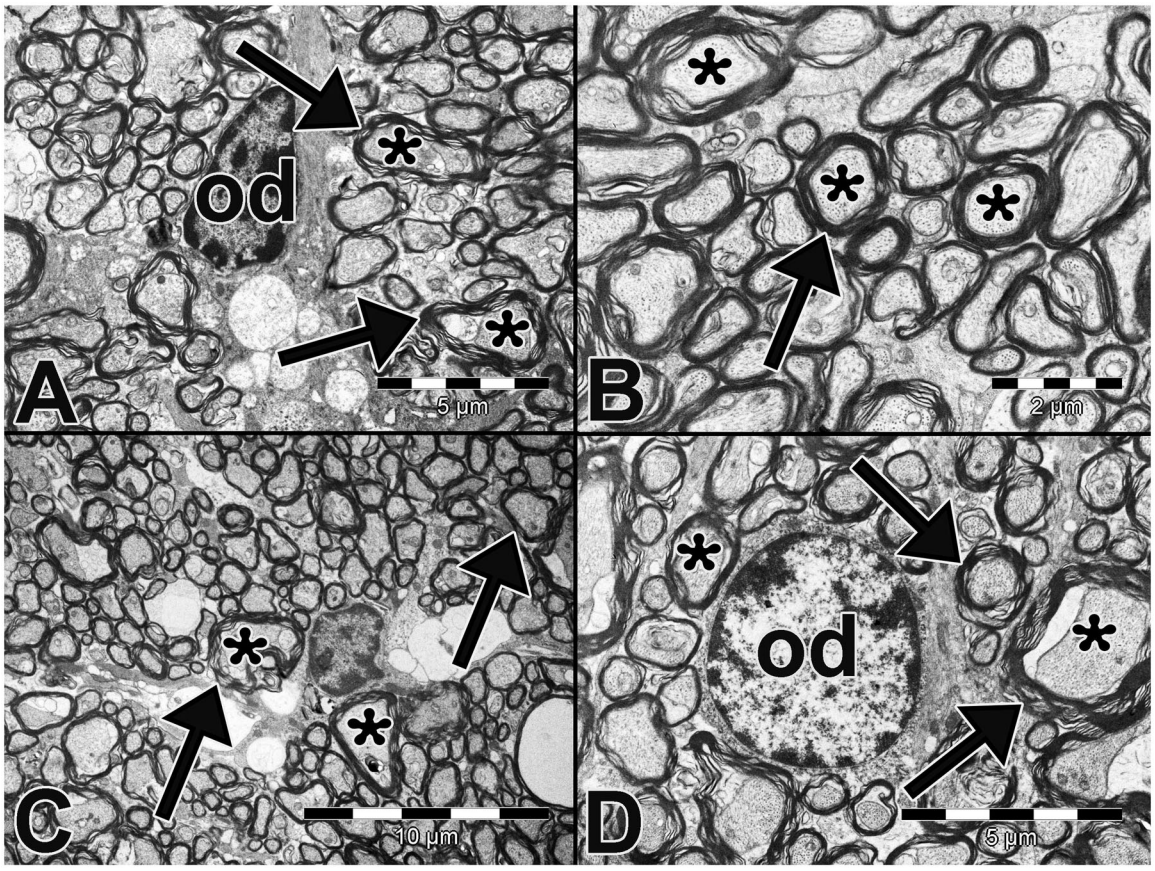


Figure 5. Optic nerve tissues were examined with transmission electron microscope. Ultrastructural micrographs of sham (A and B) and experimental group (C and D). Axon (asterisk), myelin sheath (arrow) and oligodendrocyte (od). (A) ×7500, (B) ×15000, (C) ×5000, (D) ×10000.

latency changes. Also it is observed that the wave amplitudes significantly decreased in the experimental group when compared to the sham group. The decrease in N2, P3, P2-N2 and N2-P3 was 67%, 79%, 53% and 73.5%, respectively. Except P3 latency, no abnormal conduction time was observed in the experimental group. In the RF exposed group, P3 latency shortened. There are limited studies on the effects of RF radiation emitted from mobile phone on the VEP. In a pilot study, the authors investigated the effect of a single short acute exposure to the mobile phone (5 min), using VEP examination for assessing central nerves dysfunction. Their study group consisted 20 healthy persons and they did not observe any statistically significant effects on latencies and amplitudes of VEP in case of the exposure to the electromagnetic field emitted by the mobile phone[42]. In another preliminary study conducted on 9 healthy male subjects, it was observed that VEP wave amplitudes decreased and VEP latencies were prolonged after acute exposure to cell phone radiation[8]. In a recent study, the authors investigated the duration effects of 2100-MHz RF on VEP. The rats were exposed to 2100-MHz RF for 2 h/day for 1 or 10 weeks. Shortening of latencies for all VEP components were observed in the 1 week exposed rats, whereas latencies of all VEP components, except P1, were prolonged in the 10 weeks exposed rats. They suggested that short-term RF could provide protective effects, on the other hand, long-term RF could have an adverse effect on VEPs[43].

RF exposure modifies the cellular balance by generating free radicals. Overproduction of free radicals can damage cellular components, mainly lipids in membranes and nucleic acids. In addition, free radicals can damage cells by consuming enzymatic and non-enzymatic antioxidants and triggering progressive dysfunction and genotoxic events[44]. The most often used indexes of oxidative stress are to measure level of MDA and activity of antioxidant enzymes such as SOD and CAT[44]. SOD is the first step of defense mechanism against free radicals and catalyses the dismutation of the superoxide anion into hydrogen peroxide. Then, hydrogen peroxide can be converted into H_2O and O_2 by CAT[45]. In the present study, we measured MDA level, SOD and CAT activities and observed an increase in MDA level by 118% and a decrease in SOD, CAT activity 108% and 116%, respectively in the optic nerve of the experimental group. Previous studies mentioned that celluar oxidative stress that depends on break of antioxidant defense mechanisms in different tissues such as testis[46], skin[47], sciatic nerve[7], brain[48], liver[49] and blood[50] can be leaded by RF exposure. In addition, there are some studies suggested that RF radiation causes oxidative stress in the eye tissues. MDA level and activity of SOD, GSH-Px and CAT in lens and corneal tissues are determined by researchers in order to investigate RF radiation effects in these tissues[51]. Their findings suggest that RF radiation leads to oxidative stress in corneal and lens tissues. Another study, in which

MDA level and SOD, CAT and GSH-Px activities were measured in retinal tissue, reported that SOD, CAT and GSH-Px activities were decreased and MDA level was increased[52]. Ni et al. determined oxidative stress in human lens epithelial B3 cells exposed to RF fields and they found that reactive oxygen species and MDA levels increased significantly in the RF exposed cells[53]. In the present study, we measured oxidative stress in optic nerve. To best our knowledge, there is no study in the literature that investigates the oxidative effect of RF radiation on the optic nerve. In our study, it was shown for the first time that RF radiation causes oxidative damage in the optic nerve.

In our study, in order to determine the relationship between VEP changes and biochemical changes with morphological alterations in the optic nerve, ultrastructural examination of the optic nerve was also performed. Based on both light and electron microscopic findings, it is possible to say that LTE-Advanced Pro mobile phone did not lead to a change in the structure of the optic nerve. In ultrastructural evaluation, myelinated nerve fibres and glial cells had normal appearance in sham and RF exposed groups. However, in the morphometric analysis, we observed that the axon diameter decreased by 10.2%, the myelin thickness decreased by 25.7%, and G-ratio increased by 37% in the RF exposed group compared to sham exposed group. When the myelin sheath is thinner, the G-ratio tends to go towards one, while axonal degeneration tends to go to zero when it is almost completely lost[35]. The morphometric findings obtained in the present study indicate that RF radiation causes degeneration in the optic nerve. In the literature, there is no study investigating histological and morphometric changes caused by RF in the optic nerve. However, several studies have investigated histopathological changes in various ocular tissues. In these studies, the exposure resulted in impaired retinal growth[54], hyperpigmentation of retinal pigment epithelium[55], structural changes in the retina[28,56] and lens[57,58]. However, several studies showed no histopathological changes in the various ocular tissues[27,59]. In this study, it has been shown for the first time that RF radiation causes degeneration by reducing axon diameter and myelin sheath thickness in optic nerve fibres.

As it is known, RF waves have thermal and non-thermal effects and these effects are very important for living organisms. In the present study, body surface temperature was measured before and after exposure and observed that there was no significant differences in surface body temperature between sham and RF exposed groups. This finding suggests that the damage caused by RF radiation to the optic nerve was caused by non-thermal effects, not thermal. One of the non-thermal effects of RF is that it causes oxidative stress[43,44]. One of the results shown for the first time in this study is that RF radiation causes significant oxidative stress increase in the optic nerve. When all these findings are evaluated together, it is thought that LTE-Advanced Pro RF radiation causes oxidative damage in the optic nerve and this damage causes morphometric and functional changes together with optic nerve degeneration. The high correlation between VEP wave amplitudes and oxidative stress markers also supports this argument.

Conclusion

In the present study, for the first time, it was shown that exposition to 4.5 G mobile phone radiation for 2 h/day for 6 weeks causes optic nerve damage. The optic nerve transmits all visual information to the visual cortex, and any damage in this nerve can cause permanent and serious vision loss. This study demonstrated that RF exposure may be an environmental risk factor for eye toxicity and potential eye disorders. Further studies are needed to reveal the potentiality of the risk in this area.

Disclosure statement

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