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# Immunohistopathologic demonstration of deleterious effects on growing rat testes of radiofrequency waves emitted from conventional Wi-Fi devices

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**KEYWORDS**
Carcinogenesis tests;
Infertility;
Internet;
Oxidative stress;
Wireless technology;
Testes

**Abstract** *Objective:* To investigate effects on rat testes of radiofrequency radiation emitted from indoor Wi-Fi Internet access devices using 802.11.g wireless standards.
*Methods:* Ten Wistar albino male rats were divided into experimental and control groups, with five rats per group. Standard wireless gateways communicating at 2.437 GHz were used as radiofrequency wave sources. The experimental group was exposed to radiofrequency energy for 24 h a day for 20 weeks. The rats were sacrificed at the end of the study. Intracardiac blood was sampled for serum 8-hydroxy-2′-deoxyguanosine levels. Testes were removed and examined histologically and immunohistochemically. Testis tissues were analyzed for malondialdehyde levels and prooxidant–antioxidant enzyme activities.
*Results:* We observed significant increases in serum 8-hydroxy-2′-deoxyguanosine levels and 8-hydroxyguanosine staining in the testes of the experimental group indicating DNA damage due to exposure ($p < 0.05$). We also found decreased levels of catalase and glutathione peroxidase activity in the experimental group, which may have been due to radiofrequency effects on enzyme activity ($p < 0.05$).

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# Use of laptop computers connected to internet through Wi-Fi decreases human sperm motility and increases sperm DNA fragmentation

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**Objective:** To evaluate the effects of laptop computers connected to local area networks wirelessly (Wi-Fi) on human spermatozoa.
**Design:** Prospective in vitro study.
**Setting:** Center for reproductive medicine.
**Patient(s):** Semen samples from 29 healthy donors.
**Intervention(s):** Motile sperm were selected by swim up. Each sperm suspension was divided into two aliquots. One sperm aliquot (experimental) from each patient was exposed to an internet-connected laptop by Wi-Fi for 4 hours, whereas the second aliquot (unexposed) was used as control, incubated under identical conditions without being exposed to the laptop.
**Main Outcome Measure(s):** Evaluation of sperm motility, viability, and DNA fragmentation.
**Result(s):** Donor sperm samples, mostly normozoospermic, exposed ex vivo during 4 hours to a wireless internet-connected laptop showed a significant decrease in progressive sperm motility and an increase in sperm DNA fragmentation. Levels of dead sperm showed no significant differences between the two groups.
**Conclusion(s):** To our knowledge, this is the first study to evaluate the direct impact of laptop use on human spermatozoa. Ex vivo exposure of human spermatozoa to a wireless internet-connected laptop decreased motility and induced DNA fragmentation by a nonthermal effect. We speculate that keeping a laptop connected wirelessly to the internet on the lap near the testes may result in decreased male fertility. Further in vitro and in vivo studies are needed to prove this contention. (Fertil Steril® 2012;■:■–■. ©2012 by American Society for Reproductive Medicine.)
**Key Words:** Laptop computer, Wi-Fi, sperm quality, fertility, sperm DNA fragmentation

In recent years, the use of portable computers (laptops, connected to local area networks wirelessly, also known as Wi-Fi) has increased dramatically. Laptops have become indispensable devices in our daily life, offering flexibility and mobility to users. People using Wi-Fi may be exposed to radio signals absorbing some of the transmitted energy in their bodies. Portable computers are commonly used on the lap (1–3), therefore exposing the genital area to radio frequency electromagnetic waves (RF-EMW) as well as high temperatures (3, 4).

Infertility is a common worldwide condition that affects more than 70 million couples of reproductive age (5). It has been suggested that male fertility has declined during the past several decades (6). Such decline has been attributed to the direct or indirect exposure to certain environmental factors such as RF-EMW (7).

Extremely low frequency magnetic fields can initiate a number of biochemical and physiological alterations in biological systems of different species (8–12). Many of these effects have been associated with free-radical production (13, 14). Free radicals are causative factors of oxidative damage of cellular structures and molecules such as lipids, proteins, and nucleic acids. Free radicals react with polyunsaturated fatty acids in cell membranes promoting a process called lipid peroxidation. In human spermatozoa the presence of unesterified polyunsaturated fatty acids is causally associated with the induction of reactive oxygen species (ROS) generation and lipid peroxidation (15). Damage may occur at the membrane level, leading to immotility and cell death, or at the DNA level. DNA integrity is essential to normal conception. Sperm DNA fragmentation has been associated with impaired fertilization, poor embryonic development, high rates of miscarriage, and increased incidence of morbidity in the offspring, including childhood cancer (16, 17). It has been proposed that genetic and

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LARYNGOLOGY

# Modulation of wireless (2.45 GHz)-induced oxidative toxicity in laryngotracheal mucosa of rat by melatonin

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**Abstract** It is well known that oxidative stress induces larynx cancer, although antioxidants induce modulator role on etiology of the cancer. It is well known that electromagnetic radiation (EMR) induces oxidative stress in different cell systems. The aim of this study was to investigate the possible protective role of melatonin on oxidative stress induced by Wi-Fi (2.45 GHz) EMR in laryngotracheal mucosa of rat. For this purpose, 32 male rats were equally categorized into four groups, namely controls, sham controls, EMR-exposed rats, EMR-exposed rats treated with melatonin at a dose of 10 mg/kg/day. Except for the controls and sham controls, the animals were exposed to 2.45 GHz radiation during 60 min/day for 28 days. The lipid peroxidation levels were significantly ($p < 0.05$) higher in the radiation-exposed groups than in the control and sham control groups. The lipid peroxidation level in the irradiated animals treated with melatonin was significantly ($p < 0.01$) lower than in those that were only exposed to Wi-Fi radiation. The activity of glutathione peroxidase was lower in the irradiated-only group relative to control and sham control groups but its activity was significantly ($p < 0.05$) increased in the groups treated with melatonin. The reduced glutathione levels in the mucosa of rat did not change in the four groups. There is an apparent protective effect of melatonin on the Wi-Fi-induced oxidative stress in the laryngotracheal mucosa of rats by inhibition of free radical formation and support of the glutathione peroxidase antioxidant system.

**Keywords** Melatonin · Larynx · Trachea · Oxidative stress · Wireless devices

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## Introduction

Wireless devices usages in industrial, scientific, medical, military and domestic applications, with potential leakage, of such radiation into the environment have increased by leaps and bounds in past decade [1]. From being a luxury and limited to the wealthy, wireless devices especially near 2.45 GHz is indispensable in daily lives [2]. However, every technological advance and its overuse possess possible adverse effects [3].

Exposure to electromagnetic radiation (EMR) induces degenerative effects via two ways, namely directly or indirectly. Direct effects of EMR induce production of reactive oxygen species (ROS), including superoxide anion, hydrogen peroxide, and hydroxyl radicals. The ROS contribute to tissue and DNA damages [1]. Exposure to 2.45 GHz EMR causes an increase in lipid peroxidation levels and a decrease in the activity of enzymes that prevent or protect against lipid peroxidation in tissues [4, 5]. The human cells have nonenzymatic and enzymatic antioxidant systems against degenerative effects of ROS. Glutathione

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# Effects of Selenium and L-Carnitine on Oxidative Stress in Blood of Rat Induced by 2.45-GHz Radiation from Wireless Devices

**Nurhan Gumral · Mustafa Naziroglu · Ahmet Koyu · Kurtulus Ongel · Omer Celik · Mustafa Saygin · Mesud Kahriman · Sadettin Caliskan · Mustafa Kayan · Osman Gencel · Manuel F. Flores-Arce**

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**Abstract** The levels of blood lipid peroxidation, glutathione peroxidase, reduced glutathione, and vitamin C were used to follow the level of oxidative damage caused by 2.45 GHz electromagnetic radiation in rats. The possible protective effects of selenium and L-carnitine were also tested and compared to untreated controls. Thirty male Wistar Albino rats were equally divided into five groups, namely Groups $A_1$ and $A_2$: controls and sham controls, respectively; Group B: EMR; Group C: EMR + selenium, Group D: EMR + L-carnitine. Groups B–D were exposed to 2.45 GHz electromagnetic radiation during 60 min/day for 28 days. The lipid peroxidation levels in plasma and erythrocytes were significantly higher in group B than in groups $A_1$ and $A_2$ ($p<0.05$), although the reduced glutathione and glutathione peroxidase values were slightly lower in erythrocytes of group B compared to

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# Provocation study using heart rate variability shows microwave radiation from 2.4 GHz cordless phone affects autonomic nervous system

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**Abstract**

***Aim:*** **The effect of pulsed (100 Hz) microwave (MW) radiation on heart rate variability (HRV) was tested in a double blind study.** ***Materials and Methods:*** **Twenty-five subjects in Colorado between the ages of 37 to 79 completed an electrohypersensitivity (EHS) questionnaire. After recording their orthostatic HRV, we did continuous real-time monitoring of HRV in a provocation study, where supine subjects were exposed for 3-minute intervals to radiation generated by a cordless phone at 2.4 GHz or to sham exposure.** ***Results:*** **Questionnaire: Based on self-assessments, participants classified themselves as extremely electrically sensitive (24%), moderately (16%), slightly (16%), not sensitive (8%) or with no opinion (36%) about their sensitivity. The top 10 symptoms experienced by those claiming to be sensitive include memory problems, difficulty concentrating, eye problems, sleep disorder, feeling unwell, headache, dizziness, tinnitus, chronic fatigue, and heart palpitations. The five most common objects allegedly causing sensitivity were fluorescent lights, antennas, cell phones, Wi-Fi, and cordless phones. Provocation Experiment: Forty percent of the subjects experienced some changes in their HRV attributable to digitally pulsed (100 Hz) MW radiation. For some the response was extreme (tachycardia), for others moderate to mild (changes in sympathetic nervous system and/or parasympathetic nervous system). and for some there was no observable reaction either because of high adaptive capacity or because of systemic neurovegetative exhaustion.** ***Conclusions:*** **Orthostatic HRV combined with provocation testing may provide a diagnostic test for some EHS sufferers when they are exposed to electromagnetic emitting devices. This is the first study that documents immediate and dramatic changes in both Hearth Rate (HR) and HR variability (HRV) associated with MW exposure at levels**

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**well below (0.5%) federal guidelines in Canada and the United States (1000 microW/cm$^2$).**

***Key Words*: heart rate variability, microwave radiation, DECT phone, autonomic nervous system, provocation study, sympathetic, parasympathetic, cordless phone, 2.4 GHz, electrohypersensitivity**

## Introduction

A growing population claims to be sensitive to devices emitting electromagnetic energy. Hallberg and Oberfeld[1] report a prevalence of electrohypersensitivity (EHS) that has increased from less than 2% prior to 1997 to approximately 10% by 2004 and is expected to affect 50% of the population by 2017. Whether this is due to a real increase in EHS or to greater media attention, is not known. However, to label EHS as a psychological disorder or to attribute the symptoms to aging and/or stress does not resolve the issue that a growing population, especially those under the age of 60, are suffering from some combination of fatigue, sleep disturbance, chronic pain, skin, eye, hearing, cardiovascular and balance problems, mood disorders as well as cognitive dysfunction and that these symptoms appear to worsen when people are exposed to electromagnetic emitting devices[2-7].

The World Health Organization (WHO) organized an international seminar and working group meeting in Prague on EMF Hypersensitivity in 2004, and at that meeting they defined EHS as follows[8]:

> *". . . a phenomenon where individuals experience adverse health effects while using or being in the vicinity of devices emanating electric, magnetic, or electromagnetic fields (EMFs) . . . Whatever its cause, EHS is a real and sometimes a debilitating problem for the affected persons . . . Their exposures are generally several orders of magnitude under the limits in internationally accepted standards."*

The WHO goes on to state that:

> *"EHS is characterized by a variety of non-specific symptoms, which afflicted individuals attribute to exposure to EMF. The symptoms most commonly experienced include dermatological symptoms (redness, tingling, and burning sensations) as well as neurasthenic and vegetative symptoms (fatigue, tiredness, concentration difficulties, dizziness, nausea, heart palpitation and digestive disturbances). The collection of symptoms is not part of any recognized syndrome.*"

Both provocation studies (where individuals are exposed to some form of electromagnetic energy and their symptoms are documented) and amelioration studies (where exposure is reduced) can shed light on the offending energy source and the type and rate of reaction.

Several amelioration studies have documented improvements in the behavior of students and the health and wellbeing of teachers[9], among asthmatics[10], and in both diabetics and those with multiple sclerosis[11,12] when their exposure to dirty electricity is reduced. Dirty electricity refers to microsurges flowing along electrical wires in the kHz

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# Replication of heart rate variability provocation study with 2.4-GHz cordless phone confirms original findings

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This is a replication of a study that we previously conducted in Colorado with 25 subjects designed to test the effect of electromagnetic radiation generated by the base station of a cordless phone on heart rate variability (HRV). In this study, we analyzed the response of 69 subjects between the ages of 26 and 80 in both Canada and the USA. Subjects were exposed to radiation for 3-min intervals generated by a 2.4-GHz cordless phone base station (3–8 $\mu W/cm^2$). A few participants had a severe reaction to the radiation with an increase in heart rate and altered HRV indicative of an alarm response to stress. Based on the HRV analyses of the 69 subjects, 7% were classified as being "moderately to very" sensitive, 29% were "little to moderately" sensitive, 30% were "not to little" sensitive and 6% were "unknown". These results are not psychosomatic and are not due to electromagnetic interference. Twenty-five percent of the subjects' self-proclaimed sensitivity corresponded to that based on the HRV analysis, while 32% overestimated their sensitivity and 42% did not know whether or not they were electrically sensitive. Of the 39 participants who claimed to experience some electrical hypersensitivity, 36% claimed they also reacted to a cordless phone and experienced heart symptoms and, of these, 64% were classified as having some degree of electrohypersensitivity (EHS) based on their HRV response. Novel findings include documentation of a delayed response to radiation. Orthostatic HRV testing combined with provocation testing may provide a diagnostic tool for some sufferers of EHS when they are exposed to electromagnetic emitting devices. The protocol used underestimates reaction to electromagnetic radiation for those who have a delayed autonomic nervous system reaction and it may under diagnose those who have adrenal exhaustion as their ability to mount a response to a stressor is diminished.

**Keywords:** heart rate variability, mobile phone, tachycardia, arrhythmia, microwave radiation, radio frequency radiation, electrohypersensitivity, autonomic nervous system

## Introduction

Individuals who complain of electrical hypersensitivity experience a myriad of symptoms that may include heart palpitation, arrhythmia, tachycardia, pain or pressure in the chest that may or may not be accompanied by anxiety, dizziness, nausea and headaches (Austrian Medical Association, 2012; Bevington, 2010; McCarty et al., 2011; Eltiti et al., 2007; Johansson, 2006). Since we have technology to measure the activity of

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# WI-FI ELECTROMAGNETIC FIELDS EXERT GENDER RELATED ALTERATIONS ON EEG

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***Abstract***

The present study investigated the influence of electromagnetic fields, similar to that emitted by Wi-Fi system, on brain activity. Fifteen female and fifteen male subjects performed a short memory task (Wechsler test), both without and with exposure to a 2.4GHz Wi-Fi signal. For each subject, radiation condition and electrode, the amplitude in the frequency domain of the EEG signal was calculated from the recordings of 30 scalp electrodes, using the Fourier transform.

The presence of radiation had no effect on the energies of alpha and beta band of male subjects, while it reduced these energies of female subjects, resulting in significantly lower energies, as compared to those of males.

Delta and theta band energies did not experience any noteworthy effect from gender, radiation condition and their interaction. Conversely, there was a significant interaction effect (gender x radiation) on the energies of alpha and beta rhythms.

Interestingly, this pattern was observed for a number of electrodes, which formed two distinct clusters: one located at right- anterior and the second at occipital brain areas.

The present data support the idea that Wi-Fi signal may influence normal physiology through changes in gender related cortical excitability, as reflected by alpha and beta EEG frequencies.

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ORIGINAL ARTICLE

# Drosophila oogenesis as a bio-marker responding to EMF sources

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**Abstract**

The model biological organisms *Drosophila melanogaster* and *Drosophila virilis* have been utilized to assess effects on apoptotic cell death of follicles during oogenesis and reproductive capacity (fecundity) decline. A total of 280 different experiments were performed using newly emerged flies exposed for short time daily for 3–7 d to various EMF sources including: GSM 900/1800 MHz mobile phone, 1880–1900 MHz DECT wireless base, DECT wireless handset, mobile phone-DECT handset combination, 2.44 GHz wireless network (Wi-Fi), 2.44 GHz blue tooth, 92.8 MHz FM generator, 27.15 MHz baby monitor, 900 MHz CW RF generator and microwave oven's 2.44 GHz RF and magnetic field components. Mobile phone was used as a reference exposure system for evaluating factors considered very important in dosimetry extending our published work with *D. melanogaster* to the insect *D. virilis*. Distance from the emitting source, the exposure duration and the repeatability were examined. All EMF sources used created statistically significant effects regarding fecundity and cell death-apoptosis induction, even at very low intensity levels (0.3 V/m blue tooth radiation), well below ICNIRP's guidelines, suggesting that Drosophila oogenesis system is suitable to be used as a biomarker for exploring potential EMF bioactivity. Also, there is no linear cumulative effect when increasing the duration of exposure or using one EMF source after the other (i.e. mobile phone and DECT handset) at the specific conditions used. The role of the average versus the peak E-field values as measured by spectrum analyzers on the final effects is discussed.

**Keywords**

Apoptosis, baby monitor, blue tooth, DECT base, DECT handset, Drosophila, EMFs, mobile phones, MW oven, reproduction, Wi-Fi

**History**

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## Introduction

Wireless communication devices are widely used worldwide at nearly all human activities at home, for entertainment, for education and especially at work. The related devices include the well-known cell phones (nearly 6 billion users globally), the wireless DECT telephones (no records available but apparently their number is considered very high), the wireless local area network routers (no records available), iPads which are increasingly penetrating the market having only Wi-Fi (and not wired) internet access, not to mention the baby monitors and the also newly developed "smart meters". Apart from the above "electromagnetic pollution" sources, there is also direct or indirect radiation exposure of humans by FM and TV broadcast stations, cell phone network mast stations, TETRA police and fire department antennae and many more. Because people may be adversely affected by the environmental impact of such electromagnetic fields (EMFs), it is of great scientific and social interest to explore the possible health hazards (Behari, 2010) potentially caused by this radiation spectrum. Major research is associated mainly with cell phones, while at the same time the other sources have been neglected with the exception of the epidemiological and partially clinical studies involving DECT phones (Hardell & Carlberg, 2009; Hardell et al., 2004, 2006, 2011; Khurana et al., 2010). Mobile phone-like radiation studies have been performed during the last decades investigating a variety of biological effects, in humans with clinical studies and experimental work with rodents, flies and cell cultures. Assessing the possible link between exposure to electromagnetic fields and genotoxic effects, a number of studies have reported DNA damage, cell malformations, apoptotic cell death, changes in chromatin conformation and micronucleus formation in different cell types or organisms (Lai & Singh, 1996; Lixia et al., 2006; Ruediger, 2009; Zhao et al., 2007). However, in other studies, no genotoxic effects from exposure to EMF were observed (Belyaev et al., 2006; Verschaeve, 2005).

Mobile phone radiation has been also found to cause broad changes in gene and protein expression in certain cell types (Belyaev et al., 2006; Nylund & Leszczynski, 2006; Nylund et al., 2009; Remondini et al., 2006). Our group using

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# Modulator effects of L-carnitine and selenium on wireless devices (2.45 GHz)-induced oxidative stress and electroencephalography records in brain of rat

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*(Received 8 September 2008; Revised 25 April 2009; Accepted 29 April 2009)*

**Abstract**

*Purpose*: Electromagnetic radiation (EMR) from wireless devices may affect biological systems by increasing free radicals. The present study was designed to determine the effects of 2.45 GHz EMR on the brain antioxidant redox system and electroencephalography (EEG) records in rat. The possible protective effects of selenium and L-carnitine were also tested and compared to untreated controls.

*Materials and methods*: Thirty rats were equally divided into five different groups, namely Group $A_1$: Cage control, Group $A_2$: Sham control, group B: 2.45 GHz EMR, group C: 2.45 GHz EMR + selenium, group D: 2.45 GHz EMR + L-carnitine. Groups B, C and D were exposed to 2.45 GHz EMR during 60 min/day for 28 days. End of the experiments, EEG records and the brain cortex samples were taken.

*Results*: The cortex brain vitamin A ($p < 0.05$), vitamin C ($p < 0.01$) and vitamin E ($p < 0.05$) concentrations values were lower in group B than in group A1 and A2 although their concentrations were increased by selenium and L-carnitine supplementation. Lipid peroxidation, levels were lower in group C ($p < 0.05$) and D ($p < 0.01$) than in group B where as reduced glutathione levels were higher in group C ($p < 0.05$) than in group A1, A2 and B. However, B-carotene levels did not change in the five groups.

*Conclusions*: L-carnitine and selenium seem to have protective effects on the 2.45 GHz-induced decrease of the vitamins by supporting antioxidant redox system. L-carnitine on the vitamin concentrations seems to more protective affect than in selenium.

**Keywords:** *Wireless devices, lipid peroxidation, brain, vitamin E, L-carnitine, selenium, electroencephalography records*

**Abbreviations:** ANOVA, analysis of variance; EEG, electroencephalography; EMF, electromagnetic fields; EMR, electromagnetic radiation; GSH, glutathione; GSH-Px, glutathione peroxidase; L-CAR, L-carnitine; LP, lipid peroxidation; LSD, least significance test; ROS, reactive oxygen species; SAR, specific absorption rate; SD, standard deviation; Se, selenium

## Introduction

In present times there is widespread use of 2.45 GHz irradiation-emitting devices in industrial, scientific, medical, military and domestic applications, with potential leakage of such radiation into the environment (Crouzier et al. 2007). Several studies have suggested that biological systems might be sensitive to such form of radiation (Koyu et al. 2005, Köylü et al. 2006). Today there is widespread use of 2.45 GHz radiation from common household devices likemicrowave ovens, wireless access points, and computers, which in some cases were shown to be carcinogenic (Omura and Losco 1993).

Reactive oxygen substances (ROS) are produced by a free radical chain reaction, which can also be initiated by ROS (Nazıroğlu 2007a). The ROS, i.e. singlet oxygen, superoxide anion radical and hydroxyl radical, contribute to tissue damage (Nazıroğlu 2007b). ROS also cause injury by reacting with biomolecules such as lipids, proteins and nucleic acids as well as by depleting enzymatic and/or non-enzymatic antioxidants in the brain (Halliwell 2006, Nazıroğlu et al. 2008). Memory and learning

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# 2.45-Gz wireless devices induce oxidative stress and proliferation through cytosolic $Ca^{2+}$ influx in human leukemia cancer cells

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**Abstract**

***Purpose:*** **Electromagnetic radiation from wireless devices may affect biological systems by increasing free radicals. The present study was designed to determine the effects of 2.45 GHz radiation on the antioxidant redox system, calcium ion signaling, cell count and viability in human leukemia 60 cells.**

***Materials and methods:*** **Twelve cell cultures were equally divided into two main groups as controls ($n = 6$) and irradiated ($n = 6$) and then subdivided into four different subgroups depending on the duration of exposure, namely 1, 2, 12 and 24 hours. The samples were analyzed immediately after the experimental period.**

***Results:*** **The extent of lipid peroxidation, cytosolic free $Ca^{2+}$ and cell numbers were higher in 2.45 GHz groups than in the controls. The increase of cytosolic free $Ca^{2+}$ concentrations was radiation time-dependent and was highest at 24-h exposure. The reduced glutathione, glutathione peroxidase, vitamin C and cell viability values did not show any changes in any of the experimental groups. 2-aminoethyl diphenylborinate inhibits $Ca^{2+}$ ions influx by blockage of the transient receptor potential melastatin 2.**

***Conclusions:*** **2.45 GHz electromagnetic radiation appears to induce proliferative effects through oxidative stress and $Ca^{2+}$ influx although blocking of transient receptor potential melastatin 2 channels by 2-aminoethyl diphenylborinate seems to counteract the effects on $Ca^{2+}$ ions influx.**

**Keywords:** Wireless devices, oxidative stress, $Ca^{2+}$ influx, TRPM2 channels, blood cancer

## Introduction

In present times there is widespread use of 2.45 GHz irradiation-emitting devices in industrial, scientific, medical, military and domestic applications, with potential leakage of such radiation into the environment (Crouzier et al. 2007). Common household devices like microwave ovens, wireless access points, and computers were in some cases shown to be carcinogenic (Omura and Losco 1993). Other studies have suggested that biological systems might be sensitive to such form of radiation (Nazıroğlu and Gümral 2009, Nazıroğlu et al. 2012, Gümral et al. 2009).

Reactive oxygen species (ROS) are produced by a free radical chain reaction, which in some cases can be auto-initiated (Nazıroğlu 2007a, 2007b). These species cause injury by reacting with lipids, proteins and nucleic acids as well as by depleting antioxidants in cancer cells (Reuter et al. 2010). There are various antioxidant mechanisms in cells that neutralize the harmful effects of ROS. In contrast, exposure to electromagnetic radiation (EMR) results in increases of ROS due to loss of efficiency of antioxidants mechanisms and alterations in mitochondrial electron transfer chain (Kovacic and Somanathan 2008).

Glutathione peroxidase is responsible for the reduction of hydro- and organic peroxides in the presence of reduced glutathione (Whanger 2001). Vitamin C is a free radical scavenger that also transforms vitamin E to its active form (Nazıroğlu 2007a). We recently reported that 2.45 GHz radiation induced oxidative stress in brain and blood cells of rats (Nazıroğlu and Gümral 2009, Gümral et al. 2009). However, whether 2.45 GHz EMR also induces oxidative stress in cancer cells is still unknown and deserves further study.The homeostasis of $Ca^{2+}$ ions is one of the most important factors of cellular physiological function. It is involved in such diverse functions as cellular proliferation, apoptosis, induction of oxidative stress and physiological signal transductions (Putney 2009). The cytosolic free calcium ion concentration $[Ca^{2+}]_i$ is controlled by a number of membrane-bound ion channels located both in the plasma and intracellular membranes. Transient receptor potential (TRP) channels are a group of non-selective cation channels that play important functions in sensory neurons (Nazıroğlu 2011a). One subgroup of TRP melastatin is TRP melastatin 2 (TRPM2), which has two distinct domains with one functioning as an ion channel and the other as an adenosine diphosphate ribose-specific

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# Melatonin modulates wireless (2.45 GHz)-induced oxidative injury through TRPM2 and voltage gated $Ca^{2+}$ channels in brain and dorsal root ganglion in rat

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ABSTRACT

We aimed to investigate the protective effects of melatonin and 2.45 GHz electromagnetic radiation (EMR) on brain and dorsal root ganglion (DRG) neuron antioxidant redox system, $Ca^{2+}$ influx, cell viability and electroencephalography (EEG) records in the rat. Thirty two rats were equally divided into four different groups namely group A1: Cage control, group A2: Sham control, group B: 2.45 GHz EMR, group C: 2.45 GHz EMR + melatonin. Groups B and C were exposed to 2.45 GHz EMR during 60 min/day for 30 days. End of the experiments, EEG records and the brain cortex and DRG samples were taken. Lipid peroxidation (LP), cell viability and cytosolic $Ca^{2+}$ values in DRG neurons were higher in group B than in groups A1 and A2 although their concentrations were increased by melatonin, 2-aminoethyldiphenyl borinate (2-APB), diltiazem and verapamil supplementation. Spike numbers of EEG records in group C were lower than in group B. Brain cortex vitamin E concentration was higher in group C than in group B. In conclusion, Melatonin supplementation in DRG neurons and brain seems to have protective effects on the 2.45 GHz-induced increase $Ca^{2+}$ influx, EEG records and cell viability of the hormone through TRPM2 and voltage gated $Ca^{2+}$ channels.

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## 1. Introduction

In present times there is widespread use of 2.45 GHz irradiation-emitting devices in industrial, scientific, medical, military and domestic applications, with potential leakage of such radiation into the environment [1]. Several studies have suggested that biological systems might be sensitive to such form of radiation [2,3]. Today there is widespread use of 2.45 GHz radiation from common household devices like microwave ovens, wireless access points, and computers, which in some cases were shown to be carcinogenic [4].

Reactive oxygen substances (ROS) are produced by a free radical chain reaction, which can also be initiated by ROS [5]. ROS also cause injury by reacting with biomolecules such as lipids, proteins and nucleic acids as well as by depleting enzymatic antioxidant such as glutathione peroxidase (GSH-Px) and/or nonenzymatic antioxidants such as reduced glutathione (GSH), vitamins A, C, E and β-carotene in the brain and neuronal cells [6]. Pain and brain diseases are impaired in individuals with brain and sensory neuron-related neurodegenerative diseases; this is believed to be, in part, the result of excessive production of ROS [7]. The brain and neurons consume the highest amount of oxygen in the human body [6] although most of the oxygen used in brain tissues is converted to $CO_2$ and water, small amounts of oxygen form ROS [5]. The existence of polyunsaturated fatty acids which are targets of the ROS in the brain makes this organ more sensitive to oxidative damage [8]. ROS may be involved in the action of cell phone-induced electromagnetic radiation (EMR) on biological systems [2,9–11].

Neuropathic pain states severely limit the quality of life. There are several types of sensory neurons in dorsal root ganglion (DRG) neurons with responsiveness to different kinds of external and internal stimuli. These stimuli such as nociceptive, thermal and mechanical activate different receptors and ion channels that are present in the nerve terminals at the sensory receptive fields. Their expression in selective subsets of DRG neurons determines the response profile of individual neurons to a given stimulus [12]. $Ca^{2+}$ homeostasis is one of the most important factors of cellular physiological function. It

*Abbreviations:* 2-APB, 2-aminoethyldiphenyl borinate; DRG, dorsal root ganglion; EEG, electroencephalography; EMF, electromagnetic fields; EMR, electromagnetic radiation; FFA, flufenamic acid; GSH, glutathione; GSH-Px, glutathione peroxidase; LP, lipid peroxidation; ROS, reactive oxygen species; SAR, specific absorption rate.

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ORIGINAL ARTICLE

# Protective effects of melatonin against oxidative injury in rat testis induced by wireless (2.45 GHz) devices

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**Keywords**
Melatonin—oxidative stress—rat—testis—wireless devices

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## Summary

Wireless devices have become part of everyday life and mostly located near reproductive organs while they are in use. The present study was designed to determine the possible protective effects of melatonin on oxidative stress–dependent testis injury induced by 2.45-GHz electromagnetic radiation (EMR). Thirty-two rats were equally divided into four different groups, namely cage control (A1), sham control (A2), 2.45-GHz EMR (B) and 2.45-GHz EMR+melatonin (C). Group B and C were exposed to 2.45-GHz EMR during 60 min day$^{-1}$ for 30 days. Lipid peroxidation levels were higher in Group B than in Group A1 and A2. Melatonin treatment prevented the increase in the lipid peroxidation induced by EMR. Also reduced glutathione (GSH) and glutathione peroxidase (GSH-Px) levels in Group D were higher than that of exposure group. Vitamin A and E concentrations decreased in exposure group, and melatonin prevented the decrease in vitamin E levels. In conclusion, wireless (2.45 GHz) EMR caused oxidative damage in testis by increasing the levels of lipid peroxidation and decreasing in vitamin A and E levels. Melatonin supplementation prevented oxidative damage induced by EMR and also supported the antioxidant redox system in the testis.

## Introduction

There is widespread use of 2.45-GHz irradiation emitting wireless devices in industrial, scientific, medical, military and domestic applications, in the recent century. Therefore, the leakage of irradiation into the environment is inevitable (Wang *et al.*, 2005; Crouzier *et al.*, 2007). Studies had already shown the effects of 2.45-GHz electromagnetic radiation on different body parts like nervous system, body weight, tissue morphology and histology, blood biochemical parameters, hormones, immune system and reproductive system (Aweda *et al.*, 2003; Hossmann & Hermann, 2003; Kim *et al.*, 2007; Nazıroğlu & Gümral, 2009; Kumar *et al.*, 2011a; Saygin *et al.*, 2011). There is a consequence that exposure to electromagnetic radiation (EMR) is with enhanced production of reactive oxygen species (ROS), including superoxide anion, hydrogen peroxide and hydroxyl radicals (Murphy *et al.*, 1993; Aweda *et al.*, 2003). These species and/or other free radicals may be involved in the interactions of EMR on biological systems, but the cellular and molecular mechanisms involved in this process are not totally clear (Kim & Rhee, 2004; Gumral *et al.*, 2009; Nazıroğlu & Gümral, 2009). Some studies showed exposure to 2.45-GHz EMR may cause an increase in lipid peroxidation levels and a decrease in antioxidant enzymes that prevent or protect against lipid peroxidation (LPO) in reproductive tissues of male rats (Kumar *et al.*, 2011b).

Melatonin (N-acetyl-5-methoxy-tryptamine) is synthesised mainly by the pineal gland and has been considered a potent antioxidant, even more potent than vitamin E, which detoxifies a variety of ROS in many pathophysiological states (Pieri *et al.*, 1994; Ekmekcioglu, 2006). The direct effects of melatonin on the male reproductive system and testosterone synthesis from Leydig cells have also been examined in studies on animals. Because melatonin binding sites have been detected in the reproductive system of different species, it seems reasonable to assume that melatonin exerts its actions not only as an antioxidant but also through direct interaction with the steroidogenic cells of the reproductive organs (Oner-Iyidogan *et al.*, 2001; Armagan *et al.*, 2006).

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# EFFECTS OF WI-FI SIGNALS ON THE P300 COMPONENT OF EVENT-RELATED POTENTIALS DURING AN AUDITORY HAYLING TASK

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The P300 component of event-related potentials (ERPs) is believed to index attention and working memory (WM) operation of the brain. The present study focused on the possible gender-related effects of Wi-Fi (Wireless Fidelity) electromagnetic fields (EMF) on these processes. Fifteen male and fifteen female subjects, matched for age and education level, were investigated while performing a modified version of the Hayling Sentence Completion test adjusted to induce WM. ERPs were recorded at 30 scalp electrodes, both without and with the exposure to a Wi-Fi signal. P300 amplitude values at 18 electrodes were found to be significantly lower in the response inhibition condition than in the response initiation and baseline conditions. Independent of the above effect, within the response inhibition condition there was also a significant gender X radiation interaction effect manifested at 15 leads by decreased P300 amplitudes of males in comparison to female subjects only at the presence of EMF. In conclusion, the present findings suggest that Wi-Fi exposure may exert gender-related alterations on neural activity associated with the amount of attentional resources engaged during a linguistic test adjusted to induce WM.

*Keywords*: Wi-Fi; P300 ERP component; Hayling; gender; EMF.

## 1. Introduction

Concern of health effects due to EMF, specifically radiofrequency (RF) exposure is currently arising. Numerous studies have investigated the potential effects of EMF,

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# 2.45 GHz Microwave Irradiation-Induced Oxidative Stress Affects Implantation or Pregnancy in Mice, *Mus musculus*

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**Abstract** The present experiment was designed to study the 2.45 GHz low-level microwave (MW) irradiation-induced stress response and its effect on implantation or pregnancy in female mice. Twelve-week-old mice were exposed to MW radiation (continuous wave for 2 h/day for 45 days, frequency 2.45 GHz, power density=0.033549 mW/cm$^2$, and specific absorption rate=0.023023 W/kg). At the end of a total of 45 days of exposure, mice were sacrificed, implantation sites were monitored, blood was processed to study stress parameters (hemoglobin, RBC and WBC count, and neutrophil/lymphocyte (N/L) ratio), the brain was processed for comet assay, and plasma was used for nitric oxide (NO), progesterone and estradiol estimation. Reactive oxygen species (ROS) and the activities of ROS-scavenging

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enzymes— superoxide dismutase, catalase, and glutathione peroxidase—were determined in the liver, kidney and ovary. We observed that implantation sites were affected significantly in MW-irradiated mice as compared to control. Further, in addition to a significant increase in ROS, hemoglobin ($p<0.001$), RBC and WBC counts ($p<0.001$), N/L ratio ($p<0.01$), DNA damage ($p<0.001$) in brain cells, and plasma estradiol concentration ($p<0.05$), a significant decrease was observed in NO level ($p<0.05$) and antioxidant enzyme activities of MW-exposed mice. Our findings led us to conclude that a low level of MW irradiation-induced oxidative stress not only suppresses implantation, but it may also lead to deformity of the embryo in case pregnancy continues. We also suggest that MW radiation-induced oxidative stress by increasing ROS production in the body may lead to DNA strand breakage in the brain cells and implantation failure/resorption or abnormal pregnancy in mice.

**Keywords** Microwave radiation · Reactive oxygen species (ROS) · Nitric oxide · Antioxidant enzyme activity · Implantation failure

## Introduction

Microwaves (MW) are non-ionizing electromagnetic radiation (EMR) (wavelength ranging from 1 mm to 1 m and frequency between 0.3 and 300 GHz), which unlike ionizing radiation, do not contain sufficient energy to break the bond or chemically change the substances by ionization. In general, non-ionizing radiations are associated with two major potential hazards, i.e., electrical and biological. In recent times, the level of EMR in our environment has increased manifold due to a large-scale expansion of communication networks such as mobile phones, base stations, WLAN, Wi-Fi, Wi-MAX, etc. Radiations emitted from these modern devices are reported to induce various types of biological effects which are of great concern to human health due to its increased use in daily life. MW radiation primarily increases the temperature of the biological system, i.e., thermal effects [1], but its nonthermal effects have also been noted and studied in detail [2–8]. Nonthermal effects occur when the intensity of the MW radiation is sufficiently low so that the amount of energy involved would not significantly increase the temperature of a cell, tissue, or an organism, but may induce some physical or biochemical changes [9]. Prolonged exposure to low intensity 2.45 GHz microwave radiation may affect the cholinergic activity in the rat [2], brain development in mice [10], DNA breakage in rat brain [11], and histone kinase activity in rat [12], which results in neurological problems and reproductive disorders [13–15], in addition to changes in hematopoiesis of pregnant mice [16] and micronucleated erythrocytes in rats [17]. The International Agency for Research on Cancer has also kept radiofrequency electromagnetic fields in the list of factors causing cancer to humans. Some studies performed in this context suggest that people heavily exposed to these radiations are more prone to nonmalignant tumors [18]. It has been reported that mobile phone or cell phone radiation (a type of MW radiation) causes changes in cognitive function [19]. A German study has indicated an increase in cancer around base stations. Mobile phones use electromagnetic radiation in a microwave range (2G—900/1,800 MHz, 3G—2,100 MHz frequency band) which some believe may be harmful to human health. People living close to 2G and mostly 3G mobile phone masts or base stations frequently report symptoms of electromagnetic hypersensitivity such as dizziness, headaches, skin conditions, allergies, and many other problems. Hardell and groups [20, 21] have reported the health implications of mobile phone exposure (800–2,200 MHz). They found that cell phone users had an increased risk of

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# Selenium and L-Carnitine Reduce Oxidative Stress in the Heart of Rat Induced by 2.45-GHz Radiation from Wireless Devices

**Yasin Türker · Mustafa Nazıroğlu · Nurhan Gümral · Ömer Çelik · Mustafa Saygın · Selçuk Çömlekçi · Manuel Flores-Arce**

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**Abstract** The aim of this study was to investigate the possible protective role of selenium and L-carnitine on oxidative stress induced by 2.45-GHz radiation in heart of rat. For this purpose, 30 male Wistar Albino rats were equally divided into five groups namely controls, sham controls, radiation-exposed rats, radiation-exposed rats treated with intraperitoneal injections of sodium selenite at a dose of 1.5 mg/kg/day, and radiation-exposed rats treated with intraperitoneal injections of L-carnitine at a dose of 1.5 mg/kg/day. Except for the controls and sham controls, the animals were exposed to 2.45-GHz radiation during 60 min/day for 28 days. The lipid peroxidation (LP) levels were higher in the radiation-exposed groups than in the control and sham control groups. The lipid peroxidation level in the irradiated animals treated with selenium and L-carnitine was lower than in those that were only exposed to 2.45-GHz radiation. The concentrations of vitamins A, C, and E were lower in the irradiated-only group relative to control and sham control groups, but their concentrations were increased in the groups treated with selenium- and L-carnitine. The activity of glutathione peroxidase was higher in the selenium-treated group than in the animals that were irradiated but received no treatment. The erythrocyte-reduced glutathione and β-carotene concentrations did not change in any of the groups. In conclusion, 2.45-GHz

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electromagnetic radiation caused oxidative stress in the heart of rats. There is an apparent protective effect of selenium and L-carnitine by inhibition of free radical formation and support of the antioxidant redox system.

**Keywords** 2.45-GHz electromagnetic radiation · Oxidative stress · Antioxidant enzymes · Antioxidant vitamins · L-Carnitine · Selenium

## Introduction

Many devices that emit 2.45-GHz radiation are in use for industrial, scientific, medical, military, and domestic purposes present a potential health and environmental problem [1]. Several studies have suggested that biological systems could exhibit a specific sensitivity to 2.45-GHz electromagnetic radiation [2–4]. Other studies were extended to electromagnetic radiation (EMR) generated from common household devices like microwave ovens, wireless access points, and computers which were also shown to have negative health effects, and that antioxidants showed a protective effect on 900-MHz mobile phone emissions [5, 6].

These types of radiation positively correlate to generation of oxygen-derived radicals (ROS) such as superoxide radical ions. The heart is the organ that consumes the greatest amount of oxygen, which makes it at greatest risk of oxidative stress and, in consequence, most susceptible to oxidative damage [1, 6, 7]. Superoxide ion radicals and other free radical species may be involved in the interactions of EMR on biological systems, but the cellular and molecular mechanisms involved in this process are still poorly understood [8, 9].

Exposure to 2.45-GHz EMR caused an increase in lipid peroxidation levels and a decrease in the activity of enzymes and vitamins that prevent or protect against lipid peroxidation in blood [8] and brain [9].

The body has enzymatic and non-enzymatic antioxidant systems. Enzymatic antioxidants neutralize excessive ROS, preventing them from damaging the cellular structure. Among those are superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GSH-Px) [10, 11]. In particular, GSH-Px is a selenium (Se)-containing enzyme responsible for the reduction of hydro- and organic peroxides in the presence of reduced glutathione (GSH) [12]. Se is also required for the catalytic activity of another critical antioxidant enzyme, mammalian thioredoxin reductase (TR). Along with vitamins C and E, Se is widely recognized as an essential part of the antioxidant system [11–13].

L-Carnitine (L-Car) is a low molecular weight compound obtained from the diet or biosynthesized from lysine and methionine. It has been identified in a variety of mammalian tissues and has an essential role in the mitochondrial oxidation of long-chain fatty acids through the action of specialized acyltransferases. Other roles for carnitine include buffering of the acyl coenzyme A/coenzyme A ratio, branched-chain amino acid metabolism, removal of excess acyl groups, and peroxisomal fatty acid oxidation [14]. L-Car has also been found to attenuate free radical-induced oxidative stress in various pathological conditions of heart [15]. The growing body of evidence about carnitine function in heart has led to increased understanding and identification of heart disorders associated with altered carnitine metabolism. However, there is no report on L-Car and 2.45 GHz-induced antioxidant redox system in heart.

There are no reports on the effects of wireless devices emitting 2.45 GHz radiation in the heart of experimental animals. The aim of the present study was to investigate the effects of

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# Wi-Fi technology – an uncontrolled global experiment on the health of mankind

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The twenty-first century is marked with exponentially increasing development of technologies that provide wireless communications. To the pollution of the atmosphere with radio and TV signals, not only satellite communications but also any varieties of the Wi-Fi networks are added. By 2010 in the USA, 285 million mobile phone subscribers have been registered (for a little bit more than 300 million inhabitants). The estimate for the world is more than 5 billion mobile phone users at approximately 7 billion people living on this planet. Approximately 2 years ago, the International Agency of Research on Cancer (IARC) classified the electromagnetic fields used in mobile communication as a possible cancerogene. This paper discusses the potential health hazard and lack of scientific assessment and regulatory actions in protection of the life on the planet.

**Keywords:** WiFi, pollution, hazard, Radiofrequency electromagnetic fields

## The problem: Ionizing versus nonionizing radiation

Contemporary science is increasingly using and investigating two physical factors such as ionizing and nonionizing radiation, with an attempt t? search for common mechanisms of action and evaluation of the public benefit and health hazard. What is common here is the word "radiation." However, from the viewpoint of physics, these are two different factors that might be found in an environment. Importantly, they act simultaneously, but are discussed separately, entirely neglecting the existing background of the other factor.

It has been well established that ionizing radiation usually provokes effects based on energetic mechanisms and ionization of tissues. This action is characterized with threshold levels and could develop within short time after irradiation. Speaking on ionizing radiation, scientists and public health experts, based on decades of investigation, have come to know about a large variety of unfavorable, potentially harmful effects that developed hours (sometimes days) after irradiation. This was well confirmed in the evaluation of health effects and care for personnel and population after Chernobyl accident a quarter of century ago (Grigoriev, 2012a,b; Sage, 2012). Throughout the world, interest was also excited by the recent Fukushima disaster in March 2011.

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