Int J Biol Med Res. 2025; 16(3): 8117-8124

Contents lists available at BioMedSciDirect Publications

International Journal of Biological & Medical Research

Journal homepage: www.biomedscidirect.com

Original Article

Effects of Exposure to Radiation from a Telecommunication Mast on Markers of Renal Function and Oxidative Stress in Rats

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ARTICLE INFO

Keywords:
Wistar rats,
radiofrequency radiation,
telecommunication base station,
power density,
oxidative stress.

ABSTRACT

The widespread use of wireless devices has led to increased exposure to electromagnetic radiation in the environment. The uncertainties revolving around the detrimental effects of non-ionizing radiation on living organisms and the protection against it remain unresolved. Thus, this study aimed to investigate the effects of exposure to radiofrequency radiation from a telecommunication base station on the kidneys of rats. Thirty (30) three-month-old rats (120–130 g) were divided into an experimental group consisting of 10 males and 10 females and placed at the foot of a triple-frequency tower, and a control group consisting of 10 rats of both sexes was kept far away from the base station for 91 days. Thereafter, the rats were sacrificed, and blood samples were taken by cardiac puncture for the assay of creatinine and urea. The left kidneys were used for photomicroscopic assessment, while the right kidneys were used for the assay of glutathione, catalase, and superoxide dismutase. The plasma creatinine of exposed female rats was significantly higher ($p = 0.001$) than that of the control rats. However, the plasma creatinine of the exposed male rats was not significantly different ($p = 0.58$) from that of the control rats. The exposed male and female rats had significantly higher urine creatinine ($p = 0.002$ and $p = 0.0001$, respectively) than that of the control rats. The plasma urea of the exposed male rats was significantly higher ($p = 0.0002$) than that of the control rats.However, no significant difference ($p = 0.07$) was seen in the plasma urea of the exposed female rats when compared with the control rats. The concentration of urea in the urine of the female exposed rats was significantly lower ($p = 0.02$) than that of the control rats, but the urea concentration in the urine of the male exposed rats was not significantly different ($p = 0.23$) from that of the control rats. The activities of GSH and CAT in the male and female exposed rats were significantly higher ($p = 0.02$ and $p = 0.02$, respectively) when compared with the control rats. The histology of the rats' kidneys revealed intact renal corpuscles and tubules with slightly widening urinary spaces. The study concluded that radiation from a telecommunication mast (TLM) induced anorexia, altered the plasma and urine creatinine and urea, and the antioxidant enzyme activities in the exposed rats. However, significant alteration was not seen in the histology of their kidneys. This suggests that the harmful effects of non-ionizing radiation from a TLM on the morphology of the kidneys of rats may require a longer period of exposure to become apparent.

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Introduction

The increased exposure to electromagnetic radiation in the environment could be traced to the extensive use of wireless devices. Mobile phones are among the most common of such wireless devices. Mobile phone communication is carried out by radio wave signals sent to and received from antennas installed inside the phone and the base station.

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Thus, base stations, also known as base transceiver stations (BTSs), transmit signals to mobile stations so that when a phone call is initiated by a mobile station to a BTS, an identification code is sent to the base station controller (BSC) and authenticated by the mobile switching center for the signal to be received [1]. To boost the received signal strength, several BTSs are deployed around communities [2,3], raising health concerns for the public, particularly for densely populated areas. Second, the constant quest for improved signal transmission rates, to unlock new economic potential, greatly contributes to these concerns [4,5].

Ionizing radiation, which spans from ultraviolet rays to high-energy gamma rays on the electromagnetic spectrum, possesses enough energy to ionize electrically neutral tissue molecules and, hence, create free radicals that are detrimental to human health. Its ability to cause cancer in humans and animals has been extensively studied and is reasonably well-understood [6].

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Non-ionizing radiation spans from visible light to radio waves whose frequencies range from ~300 to 3 × 1015 Hz. The energy emitted from non-ionizing radiation is not sufficient to cause ionization. Radiofrequency electromagnetic fields (RF-EMFs) are produced by a large variety of devices, including household electrical appliances, radiofrequency marking systems (e.g., RFIDs and burglar alarms), computers, base stations, and cell phones. They are generally perceived as not dangerous to human health based on their inability to cause ionization. Studies, however, suggest they may have deleterious effects on living organisms, and they have recently been classified by the International Agency for Research on Cancer (IARC) as possibly carcinogenic [7,8], even though the mechanism of their interaction with matter is not yet fully understood [9,10].

The uncertainties revolving around the detrimental effects of non-ionizing radiation on living organisms and the protection against it remain unresolved [11] in that the limits of allowed exposure (continuous long-term exposure) are yet to be agreed upon [12]. A study by Balmori [13] showed that the continuous emission of radiation from base stations situated in residential areas was assumed to have adverse effects on living organisms when the body's defense mechanisms were reduced.

Chauhan et al. [14] reported the adverse effects of radiation from BTSs on the functionalities of the brain, the spleen, the kidney, and the liver of rats. In a similar report, Şahin et al. [15] demonstrated that the exposure of rats to acute and chronic 900 MHz electromagnetic fields could lead to hepatic injuries, while other studies—e.g., that of Wiig, [16]—sought to develop a new framework for determining the appropriate location of telecommunication towers within the context of urban design. The exposure of rats to radiation from mobile phones has been reported to have detrimental effects on the living cells of rats, causing cell necrosis and a change in chromatin structure, thus causing the living cells to swell [17]. Also, it has been reported that radiation from mobile phones of 1900 to 2200 MHz resulted in focal hemorrhage in the liver parenchyma with dilated and congested hepatic sinusoids [18].

There have been a few studies based on interrogating residents near areas where telecommunication masts (TLMs) are installed. Some of those studies indicate that since the radiation from a TLM around an area is limited, compared to the standard provided by the non-ionization radiation body, it could be deduced that radiation from TLM antennas poses no harm to the living cells in the body. The kidney is the principal organ involved in regulating the volume and composition of the internal environment of the living cells. There are few reports on the effects of radiation from TLMs on the kidneys of rats. Thus, the present study is designed to investigate the effects of RF-EMF generated by a triple-frequency BTS on markers of renal function and oxidative stress in rats.

Materials and Methods

Ethical Approval

The protocols described in this study were reviewed and approved by the Health Ethics Research Committee, Institute of Public Health, College of Health Sciences, Obafemi Awolowo University, Ile-Ife with reference number IPHOAU/12/1658 by the EU Directive 2010/63/EU.

Experimental Procedures

Radiofrequency Signal Transmission

The mathematical model for describing wireless communication is provided by the set of partial differential equations known as Maxwell's equations of electromagnetism. The telecommunication mast (TLM) used in this study emitted radiation at three frequencies of 900, 1800, and 2100 MHz. The technical details of the TLM are summarized in Table 1.

Table 1:Technical details of the triple-frequency telecommunication mast located on Obafemi Awolowo University Campus.

Characteristics	Value
The average power of the antenna (Pr)	40W
Antenna Gain	17dBi
Distance to the area of the internet	91.44m
Frequency of operation	(900,1800, and 2100) MHz
Distance of compliance from the center of the]antenna (horizontal)	2.8732m

The electromagnetic field emitted in the environment by the TLM was measured in terms of the power density of the TLM at a given distance which allows for assessing the potential radiation hazard at a given spot. The power density (PD) for an emission frequency of 100 MHz and above, was given as [19]:

$$P_D = E^2/Z_0, \quad (1)$$

where E is the RMS value of the electric field emission, while Z0 is the impedance of free space, which has a value of 120π or 377 Ω.

The electric field generated by the TLM is directly proportional to the power received as [17]:

$$E = \sqrt{((480\pi^2 Pr)/(G\lambda^2))}, \quad (2)$$

where G is the antenna gain while λ is the emission wavelength of the TLM.
Electromagnetic Field Radiation (EMR) Measurement from the Telecommunication Mast (TLM) Electromagnetic field radiation (EMR) is generated by mobile phone base stations. The base station antennas used on the experimental site operate at 900, 1800, and 2100 MHz. These sources of transmissions are sector antennas. Base station antennas are designed for outdoor and indoor environments according to their specific coverage. The base station used in this investigation was situated outdoors.

The outdoor base stations are either macrocells providing radio coverage over varying distances with high output in the tens or hundreds of watts or microcells that provide coverage in areas where there is a high number of users. There, the mobile network requires additional coverage capacity to maintain the quality of service, for example in cities and suburban areas. The antennas that are mounted at street level in many instances are disguised as building features so that they are less visually intrusive to the public. Microcells have an output power of a few Watts, usually between 2 and 20W, and are open to public access.

To prevent the background radiation from interfering with the field emitted from the telecommunication mast (TLM), a survey of the site was regularly carried out using a survey meter. The TLM and the TES-593 electrosmog meter are depicted in Figure 1. The electrosmog is an isotropic 3-axis model smog meter that has a frequency range of 10 MHz–8 GHz with a high dynamic range.

It has a temperature response of 0–50 °C and a display resolution of 0.1 μW/m2 for the power density. It is equipped with a rechargeable lithium-ion battery and has a net weight of 250 g, which allows for handheld measurements over several hours. The electrosmog meter has a display refresh rate of 0.5 s, which allows for a continuous range measurement of the field levels. In total, twenty (20) field measurements were recorded at the end of each day. The base station was in operation for over 95% of the period of the study.





Figure 1. A telecommunication mast (TLM) at Obafemi Awolowo University (a) and (b) TES-593 model electrosmog meter.

Animal Care and Management

Thirty (30) male and female Wistar rats weighing 120–130 g (3-month-old) were obtained from the multidisciplinary laboratory of the College of Health Sciences, Obafemi Awolowo University, Ile-Ife, Nigeria. The rats were maintained following the Animal Welfare Act and the Guidelines for animal experimentation prepared by the Institutional Animal Ethical Committee.

They were allowed to acclimatize under natural light and dark cycles for one week before the start of the experiment. The transparent polycarbonate rat cage has a dimension of 290 × 220 × 140 mm^3 that allows for watching the rats' activities without touching it.

It is equipped with an electropolish stainless steel top grill with a gap of 5 mm between the wires. The top grill has a feed section where the weighed pellet feed is supplied for the rats to access from inside the cage and a drink section with a food-grade polypropylene water bottle with a capacity of 300 mL for water intake.

The rats were placed in six (6) plastic cages labeled A–F. Five males were placed in each of the cages labeled A-C while the female rats were placed into cages D–F. Group A (males) and D (females) were placed in the control room while others were placed in the experimental anechoic chamber which was 5 m from the telecommunication mast.

Control group: The rats in plastic cages A (males) and D (females) were kept at a far distance from the RF-EMF and fed for 91 days with food and water ad-libitum.

EMR group: The rats in this group (consisting of cages B, C, E, and F) were placed at a location situated 5 m from a mobile phone telecommunication mast and were fed standard pellet feed and water ad libitum. They were continuallyexposed to EMR from the base stations for 91 days and did not receive any treatment. EMR exposure was applied using a special mechanism.

Sample Collection

At the end of 91 days, the urine of the rats was collected over a period of 24 hours using carefully labeled metabolic cages where the rats were placed separately. The physical and chemical properties of the urine were determined using dipstick urinalysis strips (combi-1000). Thereafter, the rats were sacrificed under ketamine anesthesia, and blood samples were collected by cardiac puncture into lithium heparin tubes. The kidneys of the rats were excised and weighed. The left kidneys were fixed in 10% formo-saline for photomicroscopic assessment, while the right kidneys were homogenized for the assay of glutathione (GSH), catalase (CAT), and superoxide dismutase (SOD).

Food Consumption and Water Intake

The food consumption and water intake of the rats were measured with the aid of a weighing balance and measuring cylinder, respectively. The daily food and water consumed by the rats were determined by subtracting the previous weight of food and volume of water from the leftover after 24 hours.

Measurement of Plasma and Urine Creatinine and Urea

Blood samples collected in lithium heparin bottles were centrifuged at a speed of 3000 rpm for 10 min using the Centurium Scientific Model 8881 centrifuge to separate the plasma from the cells. The plasma and urine creatinine and urea concentrations were determined by standard colorimetric method using assay kits purchased from Randox laboratories (Crumlin, Antrim, UK).

Measurement of the Body and Kidney Weight

The weight of the rats was measured every three weeks using a China Camry dial spring scale (Camry, Zhongshan, China) to assess the weight loss or gain of the rats in each group, while the weight of their kidneys was determined using a Camry sensitive weighing balance (Camry, Zhejiang, China).

Creatinine Clearance (CCr)
This was determined using a standard formula:

$$CCr = UV/P, \quad (3)$$

where, U = concentration of creatinine in urine, V = urine flow rate (urine volume/collection time in mL/mins), P = concentration of creatinine in plasma.

Urinalysis Test

The physical and chemical properties of urine such as leukocyte count, bilirubin, blood, protein, glucose, ketone, pH level, and specific gravity were determined using Combi-100 urine reagent dip strips (Axiom Medical Ltd. 16 Cher bury Close, Berkshire RG 129HT, UK). This was completed by removing the reagent strip from a closed canister and completely immersing it in the urine.

While removing the strip from the urine, the edge of the strip was run against the rim of the urine container to remove excess urine. Thereafter, the strip was held in a horizontal position and brought in contact with an absorbent material. After one minute, the color change on the reagent strip was compared with the corresponding color blocks on the canister labeled at a specific point. The strip was held close to the color blocks and matched carefully.

Homogenization of Kidney Samples and Determination of Antioxidants.
This was completed by cutting the kidney samples into appropriate sizes (10–300 mg) and placing them in a red bead lysis kit according to their sizes. Those with lesser weights were kept in pink bead lysis. Then, 0.025 to 0.6 mL buffer saline solution (two volumes of buffer for every volume of samples) was added to the red bead lysis kit.

The kits were placed in a blender (Omni- micro homogenizer) with a controlled speed of 2000 rpm for 10 min to collect the supernatant, which was used for the assay of CAT, SOD, and GSH. Superoxide dismutase was determined according to the method of [20]. Aliquots of 2.5 mL buffer, 30 mM EDTA, and 300 µL 2 mM pyrogallol were added to 200 µL of supernatant. An increase in absorbance was recorded at 420 nm for 3 min using a spectrophotometer. One unit of enzyme activity represents

50% inhibition of the rate of auto-oxidation of pyrogallol as determined by a change in the absorbance/min at 420 nm. The activity of SOD was expressed as units/mg. Reduced glutathione was determined using the method described by [21]. An aliquot of 1 mL supernatant was added to 0.5 mL Ellman's reagent (10 mM). Thereafter, 2 mL of phosphate buffer was added to the resulting mixture. The yellow color that developed was read at 412 nm against a blank containing 3.5 mL phosphate buffer and standard. The concentration of GSH was expressed as mg/dL. Catalase activity was estimated according to the method described by [22]. To 50 µL of supernatant was added 450 µL of phosphate buffer (0.1 M, pH 7.4) and 500 µL of 20 mM H2O2 in a cuvette, and absorbance was determined at 240 nm for 1 min using a spectrophotometer. The molar extinction coefficient of H2O2 0.043.6 mM cm−1 was used to estimate CAT activity. One unit of activity is equal to 1 mmol of H2O2 degraded per minute, which is expressed as units/mg.

Histological Analysis

The fixed kidney samples were dehydrated in graded alcohol, cleared in xylene, and embedded in paraffin wax. The tissues were then sliced into 5–6 µm thick sections using a microtome. Thereafter, they were fixed on slides and stained with hematoxylin–eosin. The slides were examined under a light microscope (Olympus CH; Olympus, Tokyo, Japan), and photomicrographs were taken with a Leica DM 750 Camera at x 400 magnification.

Statistical Analysis

The results obtained were expressed as the mean ± standard error of the mean (SEM). Statistical analysis of data was carried out using t-test Graph pad version 5.03 (Graph Pad Software Inc., CA, USA) and Microsoft Excel, 2013 package, and $p < 0.05$ was considered significant.

RESULTS

Field Measurements

The electric field generated by the TLM can be was computed using the following Equation with the parameter's values in Table 1 as:

E_{-900}=183.79 ±4.59 V/m
E_{-1800}=263.94 ±6.60 V/m
E_{-2100}=304.77 ±7.60 V/m [5]

for the frequency values of 900, 1800, and 2100 MHz, respectively.
The values of field intensity (power density and electric field) to which the experimental rats (5 m from the base of the station) and the control rats (30 m away) were exposed, as measured by the electrosmog meter, are shown in Table 2. The reported values were the average values obtained every week for the periods of weeks 1–4, 5–7, 8–12, and 13.

The environmental background radiation of the environment was found to be in the range of 69–80 nSv/hr for the exposed and the control locations. This value is well below the recommended safe limit of 1 mSv/year of exposure to ionizing radiation. Hence, the observed changes in the rats could be solely attributed to the field exposure emanating from the TLM only.

Table 2. Measured values of electric field and power density with the electrosmog meter at the exposure location (5 m) as well as at the control location (30 m).

Avg Electric Field at Experimental Site (V/m)	Avg Power Density at Experimental Site (mW/m2)	AvgElectric Field at Control Site (V/m)	Avg Power Density atControl Site (mW/m2)
2.973	16	0.913	0.818
3.166	28	0.630	0.593
5.067	84	0.537	0.682
5.433	85	0.470	0.946

The power density and corresponding electric field were measured with the TES-593 model electrosmog meter every three weeks for (3) months.
Food Consumption (g) of the Rats Exposed to Non-Ionizing Radiation from Antennas Mounted on Telecommunication Mast (TLM)

The food consumption rate for both the control and exposed rats was measured during the 7th and 13th week of the study. After seven (7) weeks of exposure, the food consumption of the exposed male and female rats (24.00 ± 6.80 and 25.00 ± 6.50 g) was not significantly different (t = 1.387; p = 0.10 and t = 0.37; p = 0.36, respectively) from that of the control male and female rats (34.00 ± 2.50 and 27.00 ± 2.50 g). However, after thirteen (13) weeks of exposure, the food consumption of the male and female exposed rats (44.00 ± 4.00 and 35.00 ± 2.90 g) was significantly lower (t = 4.44; p = 0.001 and t = 2.83; p = 0.02, respectively) than that of the control rats (71.00 ± 4.00 and 55.00 ± 6.50 g), as shown in Tables 3 and 4.

Table 3. The food consumption (g) of the male rats exposed to non-ionizing radiation from an antenna mounted on a telecommunication mast (TLM).

Weeks	Control	Exposed
7th week	24.44 ± 6.80	34.00 ± 2.50
13th week	71.00 ± 4.60	44.00 ± 4.00 *

The values are given as mean ± SEM (n = 10), * = significantly different from control (p< 0.05).

Table 4. The food consumption (g) of the female rats exposed to non-ionizing radiation from an antenna mounted on a telecommunication mast (TLM).

Weeks	Control Rats	Exposed Rats
7th week	25.00 ± 6.50	27.50 ± 2.50
13th week	55.00 ± 6.50	35.00 ± 4.00 *

The values are given as mean ± SEM (n = 10), * = significantly different from control (p< 0.05).

Body Weight (g) of the Rats Exposed to Non-Ionizing Radiation from Antennas Mounted on Telecommunication Mast (TLM)
Consequent to the food consumption by the rats, their body weights were also monitored throughout the period of the study. The body weights of the rats were divided into four stages, namely: stages 1, 2, 3, and 4. These were measured at the start of the study, halfway into the exposure period, and at the end of the exposure period (Week 13), as summarized in Figures 2 and 3.

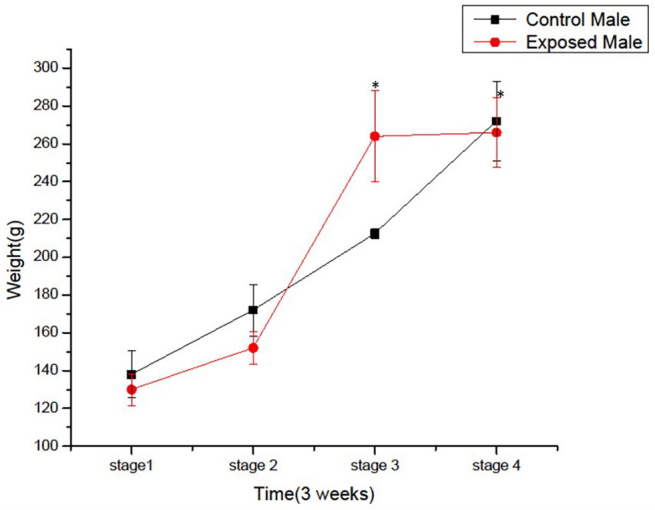


Figure 2. Graph showing the body weight (g) of the male rats. The values are given as mean ± SEM (n = 10), * = significantly different from control (p < 0.05) where Ctrl—control; Exp—exposed.

The body weights of the exposed male and female rats (110.0 ± 4.1 g and 118.0 ± 3.3 g) at stage 1 were not significantly different (t = 0.535; p = 0.31 and t = 1.375; p = 0.19, respectively) from the male and female control rats (138.0 ± 12.41 g and 130.0 ± 8.37 g). Also, there was no significant difference in the body weight of the control male and female rats (172.0

± 13.6 g and 135.0 ± 6.40 g) at stage 2 when compared with the exposed male and female rats (152 ± 8.6 g and 122.5 ± 6.30 g) (p = 0.124, t = 1.25 and p = 0.107, t = 1.05, respectively). At stage 3, the body weight of the exposed male rats (264.0 ± 24.1 g) was significantly higher (p = 0.035, t = 2.088) than that of the control male rats (212.0 ± 5.83 g).

Also, a significantly higher body weight was observed in the exposed female rats (220.0 ± 10.8 g) when compared with the control female rats (185.0 ± 2.90 g) (p = 0.01; t = 3.130). At stage 4, the control male group had a body weight (272.0 ± 21.07 g) that was not significantly different (p = 0.42; t = 0.22) in comparison with the exposed male rats (266.0 ± 18.33 g). However, a significantly lower body weight was observed in the exposed females (215 ± 2.90 g) when compared with the control females (192.2 ± 5.21 g) (p = 0.009; t = 2.800) (Figures 2 and 3).

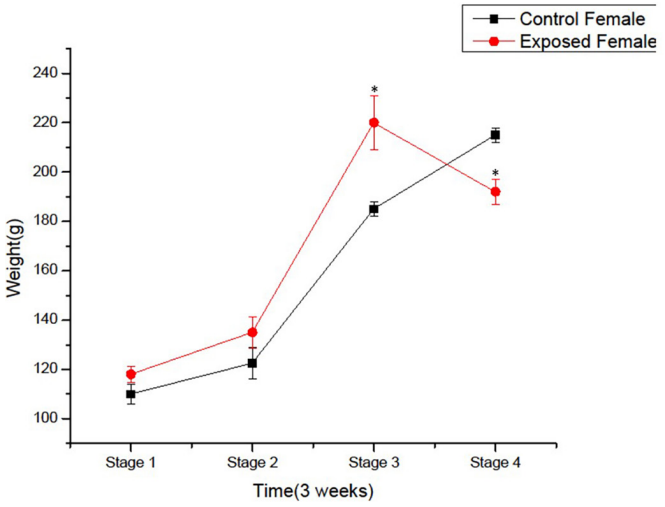


Figure 3. Graph showing the body weight (g) of the female rats. The values are given as mean ± SEM (n = 10), * = significantly different from control (p < 0.05) where Ctrl—control; Exp—Exposed.

Plasma and Urine Concentrations of Creatinine and Urea of Rats Exposed to Non-Ionizing Radiation from Antennas Mounted on Telecommunication Mast (TLM)

The plasma creatinine of male rats subjected to non-ionizing radiation (268.8 ± 31.32 mg/dL) was not significantly different (t = 0.576; p = 0.58) from that of the control group (258.6 ± 49.69 mg/dL). On the other hand, the female exposed rats had a plasma creatinine concentration (324.8 ± 58.60 mg/dL) that was significantly higher (t = 0.67; p = 0.01) than that of the control group (242.3 ± 18.46 mg/dL) (Figure 4).

The urine creatinine of the male rats exposed to non-ionizing radiation (463.4 ± 35.46 mg/dL) was significantly higher (t = 11.63; p = 0.002) in comparison with the control group (215.8 ± 14.15 mg/dL). Similarly, the exposed female rats had urine creatinine (478.8 ± 47.82 mg/dL) that was significantly higher (t = 19.28; p = 0.0001) when compared with the control female rats (181.3 ± 9.73 mg/dL) (Figure 4).

The control male rats had plasma urea (25.67 ± 1.48 mg/dL) that was significantly lower (t = 16.18; p = 0.0002) when compared with the male rats exposed to non-ionizing radiation (47.75 ± 7.15 mg/dL). Similarly, the concentration of urea present in the plasma of the control female rats (35.83 ± 2.08 mg/dL) was lower but not significantly different (t = 1.67, p = 0.067) from that of the exposed group (40.91 ± 2.23 mg/dL). The concentration of urea in the urine of the male control (27.86 ± 0.96 mg/dL) was not significantly different (t= 1.248; p = 0.23) when compared with the exposed group (27.20 ± 1.37 mg/dL). For the female rats, urea concentration in their urine (24.72 ± 1.12 mg/dL) was significantly lower (t = 2.85; p = 0.022) in comparison with the control group (32.45 ± 2.47 mg/dL) (Figure 4).

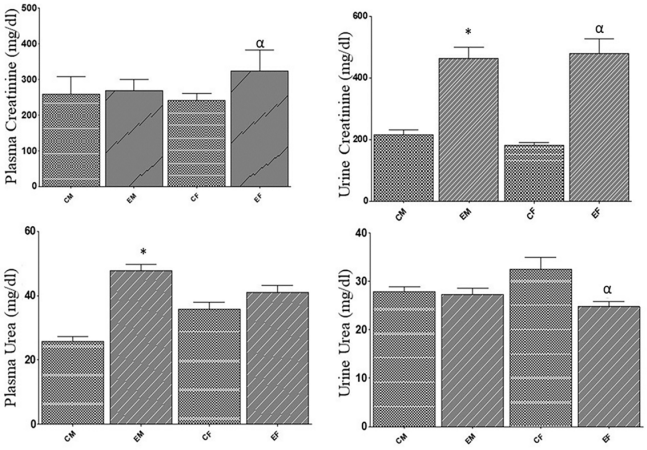


Figure 4. The effect of non-ionization on the plasma and urine creatinine and urea in the kidneys of the rats. Creatinine and urea concentrations in the blood (left and right top panels) and in the urine (left and right bottom panels) of the rats. The experimental rats (EF and EM) were exposed to an average density level of 46.73 ± 28.73 mW/m2 from a triple frequency (900, 1800, and 2100 MHz) tower, while the control rats (CM and CF) were kept away from the emission zone for 91 days. The reported values were expressed as mean ± SEM (n = 10). * = significantly different from control male (p < 0.05). A = significantly different from control female (p < 0.05).

Creatinine Clearance of Rats Exposed to Non-Ionizing Radiation from Antennas Mounted on Telecommunication Mast (TLM)

The creatinine clearance levels were computed using Equation (3). It was observed that the exposed rats of both sexes (1.56 ± 0.52 and 1.60 ± 0.66 mL/min respectively) had significantly lower (t= 2.27; p = 0.036 and t = 2.29; p = 0.034, respectively) creatinine clearance level when compared with the control groups (2.22 ± 0.76 and 2.34 ± 0.78 mL/min respectively) (Table 5).

Table 5. Creatinine clearance of rats exposed to non-ionizing radiation from antenna mounted on telecommunication mast (TLM).

CC_{CM}	2.218 ± 0.756 µL/min
CC_{EM}	1.556 ± 0.521 * µL/min
CC_{CF}	2.338 ± 0.787 µL/min
CC_{EF}	1.597 ± 0.664 α µL/min

The values are given as mean ± SEM (n = 10), * = significantly different from CCCM; α = significantly different from CCCF (p< 0.05). CCCM—creatinine clearance control male; CCCf—creatinine clearance control female; CCEM—creatinine clearance control female; CCEF—creatinine clearance experimental female.

Physical and Chemical Properties of Urine of Rats Exposed to Non-Ionizing Radiation from Antennas Mounted on Telecommunication Mast (TLM)

The urine color and appearance remained pale yellow for the control and exposed rats after the period of exposure. The specific gravity of urine and pH values are 1.005 and 8.5, respectively, for both the control and exposed rats. However, the urine volume of both the male and female exposed rats (1.3 ± 0.18 mL and 1.56 ± 0.21 mL, respectively) was significantly lower (t = 21.79; p = 0.0001 and t = 9.85; p = 0.0001 respectively) when compared with the control groups (3.83 ± 0.32 and 4.50 ± 0.92 mL, respectively). Also, there was no evidence of blood, glucose, ketone, leucocyte, and nitrile in the urine of the exposed rats when compared with the control group, while urobilinogen levels remained normal. Bilirubin was not detected in the urine of the control rats of both sexes; it was, however, found to have a level of 0.5 mg/dL in 50% of the exposed female rats and 37.5% of the exposed male rats (Table 6).

Table 6. Physical and chemical properties of urine of rats exposed to non-ionizing radiation from antenna mounted on telecommunication mast (TLM).

	Male		Female		Male		Female	
	Control	Exposed	Control	Exposed	Control	Exposed	Control	Exposed
Leucocytes	–	–	–	–	–	–	–	–
Urobilinogen	Nor	Nor	Nor	Nor	Nor	Nor	Nor	Nor
Bilirubin	–	–	–	–	–	–	–	–
Nitrite	+	+	+	+	+	+	+	+
pH	8.1 ± 0.0	8.0 ± 0.0	8.0 ± 0.0	8.3 ± 0.1	8.5 ± 0.0	8.5 ± 0.0	8.5 ± 0.0	8.5 ± 0.0
Specific Gravity	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0
Protein	3.0 ± 0.0	3.0 ± 0.0	3.0 ± 0.0	3.0 ± 0.0	3.0 ± 0.0	3.0 ± 0.0	3.0 ± 0.0	3.0 ± 0.0
Glucose	–	–	–	–	–	–	–	–
Ketone	–	–	–	–	–	–	–	–
Blood	–	–	–	–	–	–	–	–

Nor = Normal; + = present; – = Not detectable. Values are expressed as mean ± SEM. (n = 10).

Catalase (CAT), Superoxide Dismutase (SOD) and Reduced Glutathione (GSH) of Rats Exposed to Non-Ionizing Radiation from Antennas Mounted on Telecommunication Mast (TLM)

Figure 5 shows the results of the GSH, CAT, and SOD activities in the left panel, middle panel, and right panel, respectively. The GSH concentration in the kidney tissue of the male and female control rats (0.06 ± 0.01 and 0.20 ± 0.09 mmol/L) was significantly lower when compared with the exposed rats (0.55 ± 0.17 and 0.36 ± 0.04 mmol/L) (t = 4.14; p = 0.02). The SOD activities in the exposed male rats (82.08 ± 5.09 U/L) were higher but not significantly different from the control group (72.92 ± 8.31 U/L) (t = 1.468; p = 0.255).

Similarly, the exposed female rats had SOD activities (81.33 ± 2.26) that were higher but not significantly different from the control (72.33 ± 2.89 U/L) (t = 1.395; p = 0.267). The CAT activity was significantly higher in the exposed rats of both sexes (0.23 ± 0.06 U/L, and 0.24 ± 0.09 U/L) when compared with the control (0.06 ± 0.02 U/L and 0.08 ± 0.04 U/L respectively) (t = 1.94; p = 0.019 and t = 1.85, p = 0.02, respectively).

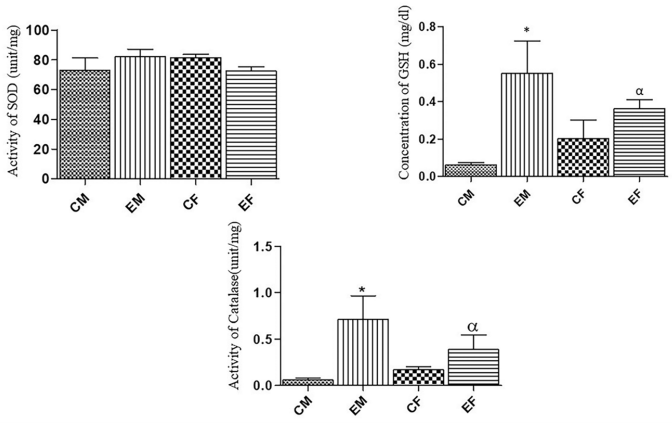


Figure 5. Level and activities of non-enzymatic and non-enzymatic antioxidants glutathione (GSH) (top right panel), catalase (middle panel), and superoxide dismutase (SOD) (top left panel) in the control rats (CM and CF) and the exposed ones (EM and EF). The reported values were expressed as mean ± SEM (n = 10). * = significantly different from the control male (p < 0.05). α = significantly different from the control female (p < 0.05).

Photomicrographs of the Renal Tissue of Rats Exposed to Non-Ionizing Radiation from Antennas Mounted on Telecommunication Mast (TLM)

Figure 6 shows the representative light micrographs of kidney sections subjected to hematoxylin and eosin stains. It was observed that the control males (CM) and control females (CF) have normal renal corpuscles with intact Bowman's capsule (BC). The simple squamous epithelium surrounds the fluid-filled urinary (Bowman's) space (US) within which is suspended a tuft of capillary, glomerulus (G). The cellular elements of the glomerulus (podocytes, endothelial and mesangial cells) appear intact. The renal tubules (Proximal and distal convoluted tubules (PCT and DCT)) also maintain normal cellularity and shape. The exposed male (EM) and the exposed female (EF) groups show normal renal corpuscles with a slightly wide urinary space (US) relative to control groups, while the proximal and distal convoluted tubules appear normal.

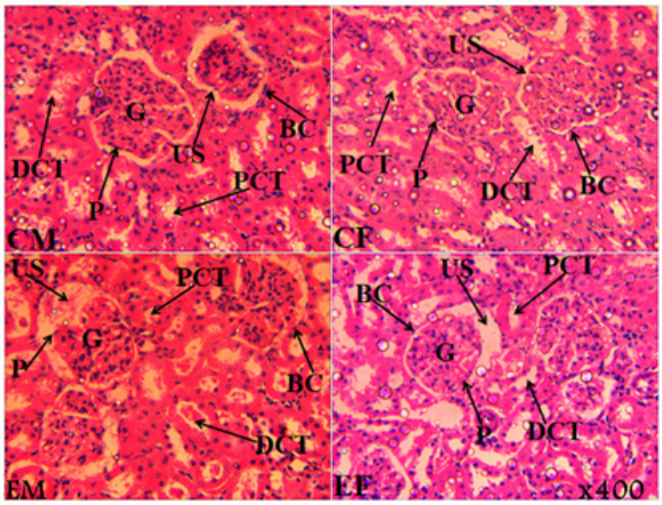


Figure 6. Micrographs of kidney sections of Wistar rats subjected to hematoxylin and eosin stains. The control male (CM) is in (the top-left panel), the control female (CF) is in the (top-right panel), (the bottom-left) shows the experimental male (EM), and the experimental female (EF) is shown in the (bottom-right panel). G—glomerulus; US—urinary space; BC—Bowman's capsule; PCT—proximal convoluted tubule; DCT—distal convoluted tubule; P—podocytes.

Discussion

In the present study, the effects of the field produced by a triple frequency (900, 1800, 2100 MHz) telecommunication tower on the functionalities of the kidneys of Wistar rats were investigated.

The inability of non-ionizing radiation to cause the direct ionization of body tissue molecules and create free radicals has made them largely underestimate the health hazards they may cause. Several investigations conducted in the last two decades suggested noticeable changes in the biological systems of humans and rats [4,13] as a result of exposure to non-ionizing radiation, albeit the underlying mechanism is yet to be understood [23,24].

Radiofrequency radiation falls within the lower half of the non-ionizing radiation frequency range (20 kHz–300 GHz) on the electromagnetic energy spectrum and therefore emits extremely low energies (8.27×10−11–1.24×10−3 eV). The erection of an extremely large number of telecommunication towers and their increasing emission frequencies has raised concerns about changes in the biological systems of humans and rats.

The observed difference in the food consumption of the rats suggests an

overall effect of a partial loss of appetite in the rats that have been exposed to a radiofrequency power density field of ~15.8–85.9 mW/m2 after 91 days. This was first manifested by an increased food consumption rate during the first half of the study period (Weeks 1–7) followed by a decrease in food consumption up to the 13th week in the exposed rats as compared with the control groups. A corresponding trend was also observed in the body weight. Thus, the decrease in body weight that was observed in the rats exposed to non-ionized radiation from the telecommunication tower could be ascribed to the decreased food intake that was seen in the rats.

The urinalysis test is used to evaluate urine for its pH, appearance, color, volume, and specific gravity. It is a useful indicator to detect and manage a wide range of urinary tract infections, kidney disease, and diabetes [25,26]. In this study, urinalysis test results suggest partial changes in the physical and chemical characteristics of the urine of exposed rats. However, bilirubin was found in the urine of the exposed rats, suggesting alteration in liver cells function or blockage of common bile duct, thereby causing the kidneys to excrete a large quantity of bilirubin into urine. This needs to be further investigated.

Among the standard physiological procedures for testing the functionalities of the kidney and checking for possible early kidney diseases is to assess the creatinine and urea concentrations in the blood and the urine [27]. Changes in creatinine and urea levels are consistent with renal impairment. Plasma creatinine and urea are used for evaluating renal function. The concentrations of these routinely used markers of renal function in the plasma depend largely on glomerular function. In renal disorders, reduced glomerular filtration rate results in elevated plasma levels of waste product of metabolism [28]. Thus, the plasma concentrations of creatinine and urea increase as the filtration rate falls. In this study, creatinine and urea were assayed in the blood and the urine of the exposed and control rats.

The rise in creatinine concentration in the blood of the exposed rats as compared with the control indicates that creatinine is produced at a fairly higher rate in the exposed rats, which is expected to be removed from the blood by the kidneys, since it is a breakdown product of muscle metabolism [29] and actively secreted by the proximal tubular cells. Its level rises in the blood if there is a defect in kidney filtrating ability, indicating remarkable damage to the nephrons. In the same vein, the high concentration of creatinine in the urine of the exposed rats as compared with the control rats not only suggests that creatinine was sufficiently filtered out of the blood but that more creatinine was produced in the exposed rats. These observations were further buttressed by the creatinine clearance rate, which was lower in the exposed rats of both sexes as compared with the controls, since creatinine clearance is a useful measure of the glomerular filtration rate.

Urea is a waste product of protein metabolism produced by the liver and excreted by the kidney as a component of urine. Urea levels in the plasma of both male and female rats after they were exposed to non-ionizing radiation from the telecommunication mast were higher compared with the control. Moreover, the urine concentration of urea was significantly lower in the exposed female rats when compared with the control rats. This may have resulted from increased urea production or increased protein catabolism, since the photomicrograph of the kidney of the exposed rats appears normal except for a slightly widening urinary space.

Oxidative stress occurs when there are irregularities or imbalance between antioxidants and free radicals in the body [30]. Free radicals are oxygen-containing molecules with uneven electron numbers, which cause a large chain of chemical reactions that can be beneficial or harmful. The antioxidants, including reduced glutathione, superoxide dismutase, and catalase, donate an electron to the free radicals to make them stable [31]. A high activity level of the first-line antioxidants [32], namely glutathione (GSH) and catalase (CAT), is indicative of increased oxidative stress. The CAT and GSH activities of rats exposed to radiofrequency radiation from TLM were significantly higher than those of the control rats.

This agrees with the study of Devrim et al., [33] who reported significantly higher CAT and GSH activities in the renal tissue homogenates of rats after 4 weeks of exposure to electromagnetic radiation when compared to the control group. Consequently, the increase in GSH and CAT that was observed in the rats exposed to radiofrequency radiation from the TLM in this study is suggestive of a response to increased peroxidation reaction in the rats. It could therefore be inferred that exposure to radiofrequency radiation from TLM directly caused oxidative stress brought about by the generation of free radicals in the kidney tissue of the rats.

It can then be concluded that the continuous exposure of rats to radiofrequency power density in the range of 15.8–85.9 mW/m2 over a period of 91 days induced anorexia and altered the plasma and urine creatinine and urea, and the antioxidant enzymes activities of the exposed rats. However, appreciable alteration was not seen in the histoarchitecture of the kidneys of the rats as revealed by their photomicrographs. This indicates that the adverse effects of non-ionizing radiation from TLM on the structure of the kidneys of rats may require a more prolonged period of exposure to become evident.

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Author Contributions: O.A.: Original draft preparation, Data curation. M.L.: Conceptualization, Supervision. R.A.: Methodology, Data Curation. O.O. (OlaoluwaOlukiran): Supervision, Writing—Reviewing and Editing. A.A.: Validation. R.I.: Validation. O.O. (OluwadareOgundipe): Data analysis, M.A.: Validation. P.T.: Validation. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The animal study protocols described in this study were reviewed and approved by the Health Ethics Research Committee, Institute of Public Health, College of Health Sciences, Obafemi Awolowo University, Ile Ife with reference number IPHOAU/12/1658 in accordance with the EU Directive 2010/63/EU.

Informed Consent Statement: Not Applicable

Data Availability Statement: The data are available upon request from the authors.

Conflicts of Interest: The authors declare no conflicts of interest for this study

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