Effects of Telecommunication Mast Electromagnetic Radiation (EMR) on Exposed Rats (*Rattus norvegicus*)

Tajudeen Yahaya[1*], Esther Oladele[2], Obaroh Israel[3], Jamilu Bala[4], Abdulhakeem Haruna[1], and Abubakar Muhammad[1]

[1] Department of Biology, Federal University Birnin Kebbi, Nigeria
[2] Biology Unit, Distance Learning Institute, University of Lagos, Nigeria
[3] Department of Animal and Environmental Biology, Kebbi State University of Science and Technology
[4] Department of Biochemistry and Molecular Biology, Federal University Birnin Kebbi, Nigeria

Abstract

Background: The safety of electromagnetic radiation (EMR) from modern telecommunication devices is controversial as some studies reported negative effects, while others reported no effects. Thus, more studies are necessary to clear the controversy, so as to design appropriate precautionary and palliative measures if found toxic.

Objective: This study was conducted to determine the effects of telecommunication mast EMR on selected health indices of rats (*Rattus norvegicus*).

Materials and Methods: Twenty-four (24) rats were divided into two groups of 12 rats each. Group 1 was made the control, while group 2 was exposed to 18000 MHz EMR at 50 m from a telecommunication mast. The weight, body temperature, reproductive activities, and reactions of the rats were observed for 60 days. Thereafter, the rats were sacrificed and their blood parameters, liver function, and histology were examined.

Results: The exposed rats were less active, weighed and reproduced less, had lower offspring survival rates and insignificantly ($P > 0.05$) elevated body temperature. The white blood cells (WBC) of the exposed rats were significantly increased ($P < 0.05$), while the packed cell volume (PCV), hemoglobin (Hb), red blood cells (RBC), and lymphocytes were reduced. The aspartate aminotransferase (AST), alkaline phosphatase (ALP), alanine aminotransferase (ALT), and total protein (TP) of the exposed rats were significantly increased, while the albumin (ALB) was significantly reduced. The ovary, lung, and kidney tissues of the exposed rats showed no abnormalities, but necrosis of the hepatocytes and fat were observed in their livers and the skins, respectively.

Conclusion and Recommendation: It is concluded that electromagnetic radiation (EMR) from modern telecommunication devices harmed the health of exposed rats. It is inferred from the results that EMR has negative effects on the health of mammals. Hence, it is advisable not to site telecommunication masts close to dwelling places.

Keywords: EMR; Lymphocytes; Necrosis; PCV; Rat; Telecommunication mast

1. Introduction

Electromagnetic radiation (EMR) is widely used in modern technologies. However, some of these devices may emit EMR strong enough to induce toxicity in biological systems, thus necessitating their safety evaluation. EMR is an energy that moves in waves and takes many forms, such as radio waves, microwaves, heat waves, ultraviolet light, infrared light, x-rays, and gamma rays (Jim, 2015). Among the EMR forms, gamma rays have the shortest wavelength, being less than a nanometer, while radio waves have the longest wavelength, being more than a nanometer (Jim, 2015). The length of the wavelength is inversely proportional to the amount of energy. Thus, short-wavelength radiations have more energy than long-wavelengths (Cleaver *et al*., 2010). As such, gamma rays, x-rays, and some ultraviolet waves with short wavelengths have a high amount of energy and frequency to knock out electrons from atoms and are termed ionizing EMR (Nagaraja, 2019). EMR such as radio waves, microwaves and heat waves have a long wavelength which results in low frequency and energy and are termed non-ionizing EMR (WHO, 2019).

Acute exposures to ionizing EMR can cause skin burns or radiation syndrome, while prolonged exposures may cause chronic diseases (WHO, 2018). These chronic diseases include cancers, mental disorders, neurologic illnesses, fetal abnormalities, cardiovascular diseases, sleep disorders, etc. (Naeem, 2014; Batool *et al*., 2019). A non-ionizing EMR can set an atom in motion but does not have enough energy to remove or alter it (USEPA, 2019). However, long-term exposure to large amounts of non-ionizing EMR may result in heat-related health hazards such as skin burns,

*Corresponding Author. E-mail: yahayatajudeen@gmail.com

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premature aging of the skin, eye damage, and skin cancer (CDC, 2015).

However, controlled EMR can be used in the hospital to treat diseases, especially to destroy cancer cells (Nagaraja, 2019). EMR is also used in academics, industry, agriculture, archaeology (carbon dating), space exploration, law enforcement, geology (e.g. mining), as well as for generating electricity, among others (USNRC, 2017). Additionally, EMR is used in modern technologies such as mobile phones, wi-fi, computer, and television.

Electromagnetic radiations have numerous sources, which are classified into natural and man-made (ACS, 2019). Natural sources include cosmic microwaves, infrared light, visible light, among others, while artificial sources include light bulbs, gas discharge lamps, x-ray machines, lasers, radiotherapy equipment, nuclear facilities, etc. (Julie *et al.,* 2014; Panagopoulos *et al.*, 2015). Modern telecommunication facilities, particularly telecommunication masts, mobile phones, among others, are some recent additions to the list of suspected EMR sources (Olatunde *et al.*, 2011). Modern telecommunication devices have helped revolutionize communication and formed part of human socioeconomic life. However, there is a controversy surrounding the safety of the EMR from mobile phone devices. While some studies like Al-Glaib *et al.* (2008) and El-Bediwi *et al.* (2011) linked mobile phone EMR to health hazards, some others like Keykhosravi *et al.* (2018) and USFG (2020) found no link. Thus, more studies are needed to clear the controversy, so as to design appropriate precautionary and palliative measures if found toxic. To this end, this study assessed the effects of telecommunication mast EMR on some exposed rats in Kalgo, Kebbi State, Nigeria.

2. Materials and Methods

2.1. Description of Study Area

The study was carried out in Kalgo, northwestern, Nigeria. Kalgo is about 15 km from Birnin Kebbi, the capital city of Kebbi State. Kalgo is a nodal town, along the intersection of Birnin Kebbi-Jega Road and Birnin Kebbi-Bunza Road on latitude 12°27'57.8808' North and longitude 4°11'58.2864' East (Figure 1). It has a telecommunication mast density of at least 20, most of which are located in residential areas. Kebbi State is bordered by Sokoto State in the north, Niger State in the south, Katsina and Zamfara State in the east as well as Niger and Benin Republic in the west. As of 2006, at least 3,256,541 people lived in the state (Population Council, 2007), mostly artisans and farmers. The natural vegetation of the state comprises a mixture of Sudan and Guinea Savannah. However, long-term anthropogenic activities have changed the natural vegetation of the state to mainly Sudan Savannah vegetation. The climate of the state is characterized by a long dry season and short wet season with an annual rainfall of about 787 mm (Yahaya *et al.*, 2020). The temperature could fall below 20 °C and rise above 40 °C.

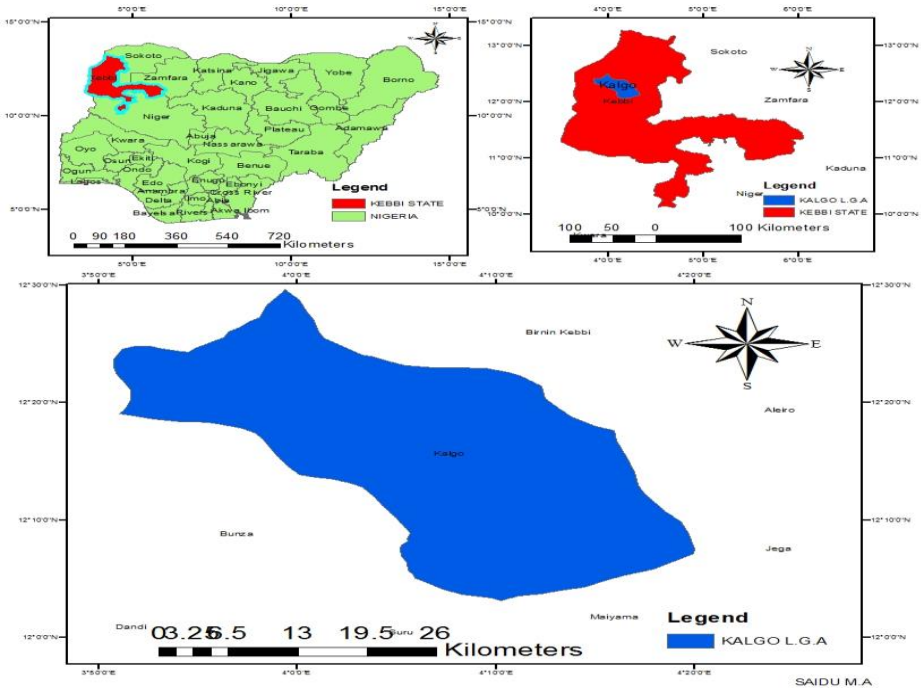


Figure 1. Locations of Kalgo, Kebbi State, Nigeria (ArcGIS 10.3 software).

2.2. Sources of Animal Samples and Management

The study was approved and conducted according to the guidelines set by the Animal Ethics Committee of Federal University Birnin Kebbi, Nigeria. Twenty-four (24) mixed-sex rats (*Rattus norvegicus*), aged 50 days and mean weight 201 ± 11 g were sourced from the Department of Biology, Federal University Birnin Kebbi in December 2019. The rats were managed in well-ventilated metal cages, under ambient conditions with a 12h light/dark cycle. The rats were allowed to acclimatize to the environment for 14 days before commencing the study. Water and pellet feeds purchased from the Vital Feed Industry, Lagos, Nigeria, were fed to the rats *ad libitum*.

2.3. Study Design

The rats were divided into two groups of 12 rats each (6 males and 6 females), of which group one was made the control and placed away (at about 1 km) from all sources of EMR. Group 2 was exposed to 18000 MHz EMR at about 50 m from a telecommunication mast (Aderoju *et al.*, 2014). The weight, reproductive activities, body temperature, and reactions of the rats were observed daily for 60 days, after which the rats were sacrificed by cervical dislocation. Blood samples were taken for hematological and liver function tests and the livers, lungs, kidneys, skins and ovaries were obtained for histopathological examination.

2.4. Procedure for Blood Collection

Each rat was held firmly while its tail was swapped with alcohol to disinfect the tail veins. The veins were then pierced with a 5 ml syringe, 20 gauge needle, and about 2.5 ml of blood was drawn slowly and transferred to bottles containing disodium ethylenediaminetetraacetic acid (Na_2EDTA).

2.5. Measurement of EMR, Body Temperature, Weight, and Reactions

The EMR around the telecommunication mast was measured using a Trifield EMR meter (model TF2) and the body temperature was measured by inserting a clinical thermometer into the rectal cavity of the rats. The weight was measured using an electronic weighing balance, while the rats' reactions were scored very active, active, or not active based on the interactions with other rats, feed intake, and mobility.

2.6. Hematological Tests

2.6.1. Determination of packed cell volume (PCV)

The PCV was determined using the micro-hematocrit centrifuge method described by Bull and Hay (2001). Two-third of a capillary tube was filled with each of the blood samples and one end of the tube was sealed using a Bunsen burner flame to prevent leakage, before and during spinning in the hematocrit centrifuge machine. The capillary tubes were labeled, arranged in the micro-hematocrit centrifuge machine, and centrifuged at 12,000 rpm for five minutes. The centrifugation separated the blood plasma from the red blood cells in the tubes, which was then measured using a micro-hematocrit reader.

2.6.2. Determination of hemoglobin (Hb)

The Hb content was measured using the cyanmethemoglobin method as described by Hope *et al.* (2019). About 0.02 ml of blood was transferred into a test tube containing 5 ml Drabkin's reagent. The solution was mixed thoroughly and allowed to stand for 10 minutes at 250 °C to allow cyan-methemoglobin to form. The mixture was then transferred into a cuvette and read on a spectrophotometer at a wavelength of 540 nm. The reading recorded was compared with a pre-calibrated chart to obtain the actual Hb values in g dl^{-1}.

2.6.3. Determination of white (WBC) and red blood cells (RBC)

The WBC and RBC were estimated using the improved Neubauer hemocytometer as described by Cheekurthy (2019). The blood samples were diluted at a ratio of 1:200 with ammonium oxalate and Hayem's solution and added to the hemocytometer chamber. The WBC being bigger was counted from the four corner squares of the chamber. To estimate the RBC, the small squares in the middle of the chamber were zoomed, and the RBC counted.

2.6.4. Determination of lymphocytes

The lymphocytes were estimated as described by Heather and Tim (2016). A drop of each blood sample was smeared on a clean glass slide and stained with a Wright-Giemsa dye, which helped differentiate the subtypes of the WBC in the sample. The number of lymphocyte cells was then calculated using an automated blood count machine.

2.7. Liver Function Tests

The liver function tests were performed from the blood serum, which was prepared as described by Henry (1979). Blood samples in covered test tubes were allowed to clot by leaving it undisturbed at room temperature for about 30 minutes. The clots were then removed by centrifuging between 1000 and 2000 x g for 10 minutes in a refrigerated centrifuge. The resulting supernatant (serum) was immediately transferred into a clean polypropylene tube using a Pasteur pipette and then used to determine the liver enzymes and proteins outlined below.

2.7.1. Determination of alanine aminotransferase (ALT)

The ALT activity was estimated by colorimetric method described by Mirmiran *et al.* (2019). A reagent, 2, 4 dinitrophenyl hydrazine was added to the blood serum, producing pyruvate hydrazine. The ALT was

measured using a Cobas Mira Plus CC Chemistry Analyzer (Switzerland) based on the colorimetric measurement of pyruvate hydrazine formed.

2.7.2. Determination of aspartate aminotransferase (AST)

The same colorimetric method used to determine the ALT activity was also used for the AST. However, the reagent, 2, 4 dinitrophenyl hydrazine was replaced with 2, 4 nitrophenyl hydrazine, producing oxaloacetate hydrazine. The colorimetric measurement of the oxaloacetate hydrazine concentration was used to estimate the AST activity.

2.7.3. Determination of alkaline phosphatase (ALP)

The ALP activity was determined using the spectrophotometric method described by Bergmeyer and Bernt (1974). About 0.02 ml of the blood serum was added to 1.0 ml diethanolamine buffer, pH 9.9, magnesium chloride (MgCl2), and a substrate, p-nitrophenyl phosphate. The mixture produced was stirred, and the absorbance was taken over 1, 2 and 3 minutes using a timer at 405 nm in a spectrophotometer. Change in absorbance taken after 2 and 3 minutes was used to determine the final absorbance of ALP.

2.7.4. Determination of total protein (TP)

The Biuret method described by Layne (1957) was used to determine the TP. About 0.02 ml of the blood serum was treated with an equal volume of 1% sodium hydroxide followed by a few drops of aqueous copper (II) sulfate. The mixture was stirred and incubated for 10 minutes at room temperature, after which the absorbance of the colored solution was read at 546 nm.

2.7.5. Determination of albumin (ALB)

The bichromatic digital endpoint method described by Kelly (1979) was used to determine the ALB concentrations. About 1.0 ml of Bromcresol purple (BCP) was added to 0.02 ml of the blood serum, producing BCP–ALB complexes. The change in the absorbance at 600 nm was measured with a spectrophotometer and considered the concentration of ALB in the sample.

2.8. Evaluation of Reproductive Performance

The reproductive performance of the rats was evaluated from the numbers of the reproductive cycle completed by females in each group and the number of offspring born per birth. The offspring survival rate in each group was also calculated by taking the percentage of the offspring that survived from the total offspring born per female.

2.9. Histopathological Examination

The histopathological examination was carried out as described by Tajudeen *et al.* (2020). About 5 mm thick samples of the selected tissues were preserved in 10% neutral buffered formalin solution to prevent putrefaction and maintain the original structures and shapes of the tissues. The tissues were then dehydrated using increasingly concentrated alcohol (60, 80, and 100%) and then embedded in paraffin wax. The embedded tissues were thereafter sectioned at 5 μm with a rotary microtome (model YR421), spread on glass slides, and air-dried. Hematoxylin and eosin dyes were used to stain the slides and viewed under a light microscope for histopathological abnormalities.

2.10. Data Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 20 for Windows. The Student's *t*-test was used to compare the differences between the test and control groups in which $P \leq 0.05$ was considered a significant difference.

3. Results and Discussion

3.1. Effects of the EMR on Rats' Weight, Body temperature and Reactions

Compared with the control, the exposed rats had insignificantly ($P > 0.05$) elevated body temperature, were less active, and weighed significantly ($P < 0.05$) less (Table 1). An earlier study by Wyde *et al.* (2018) also observed non-significant elevated body temperature in some rats exposed to mobile phone EMR. However, Forouharmajd *et al.* (2018) and Mai *et al.* (2020) reported a significantly elevated body temperature in some mice exposed to mobile phones EMR. Changes in the body temperature could result from an interaction between EMR and a primary cold sensor in mammals known as transient receptor potential cation channel subfamily melastatin member 8 (TRPM8) receptors (Mai *et al.*, 2020). The non-consistence of the mentioned studies and the present study could be due to the varied distances of the test subjects from the communication gadgets. In a survey conducted by Akintonwa *et al.* (2008), 57.72% of the participants who suffered from EMR-related diseases, including increased body temperature lived close to telecommunication masts (less than 50 m). The authors concluded that the hazards of EMR from communication devices and facilities are directly proportional to the proximity and duration of exposure.

The loss of weight observed in the exposed rats could be a sign of cytotoxic interactions between the EMR and the rat cells. According to Gye and Park (2012), EMR exposure may generate free radicals, causing cell growth inhibition, protein misfolding, and DNA breaks. Earlier studies by Aziz *et al.* (2010) and Srivastava *et al.* (2017) also reported growth retardation among some rats exposed to 900 MHz EMR from

mobile phones. However, Sani *et al.* (2018) recorded a weight increase by some rats exposed to low EMR from mobile phones, while Lee *et al.* (2004) recorded no weight gain in rats exposed to 60 MHz EMR.

Table 1. Weight, body temperature and reactions of rat exposed to telecommunication Mast EMR.

Group	Weight gain (g)	Average temperature (°C)	Reaction
Control	4.10 ± 1.1	32.10 ± 2.2	Very active
Exposed	2.30 ± 0. 8*	33.16 ± 2.4	Active

Note: Values were expressed as mean ± SD (n = 12); the value with an asterisk (*) in the column is statistically different from the control at p ≤ 0.05 (student's t-test).

3.2. Effects of the EMR on Hematological Parameters

The levels of the WBC of the exposed rats were significantly higher ($P < 0.05$) than the control, indicating that the body recruited more immune cells to fight the absorbed EMR (Table 2). Adebayo *et al.* (2019) also observed elevated WBC levels in some rats exposed to 1.40 W cm^{-2} EMR at 24 m from the base of telecommunication masts. The authors opined that the elevated WBC levels could be an indicator of self-defense mechanism against exposure to foreign bodies. In contrast to the WBC, the levels of the PCV, Hb, RBC, and lymphocytes of the exposed rats were reduced, but the reduction was significant ($P < 0.05$) only in the levels of the PCV and lymphocytes. The reduced blood parameters indicate that the rats were anemic, possibly modulated by the reduced activities noticed in the rats, which could have resulted in loss of appetite and fewer feed intakes, culminating in iron deficiency. According to Tatala *et al.* (1998), dietary iron deficiency is a major cause of anemia. The reduction in the blood parameters could also mean the EMR induced oxidative damage in the rats' blood cells. According to Adebayo *et al.* (2019), EMR exposure may induce oxidative stress in animal systems, resulting in the reduction of blood parameters. Previous studies by Singh *et al.* (2013) and Aberumand *et al.* (2016) also found significant decreases in the levels of Hb, RBC, and blood platelets of some mice exposed to mobile phone EMR. However, Sani *et al.* (2018) reported an increase in the Hb and RBC levels of some rats exposed to EMR from mobile phones.

Table 2. Blood parameters of the rats exposed to telecommunication mast EMR.

Parameter	Control	Exposed
PCV (L L^{-1})	0.28 ± 0.01	0.26 ± 0.01*
HB (g dL^{-1})	9.43 ± 2.2	8.67 ± 2.0
WBC (mc mm^{-3})	6.32 ± 1.9	11.36 ± 3.3*
RBC (mc mm^{-3})	5.30 ± 1.0	4.73 ± 1.4
LYM (c μL^{-1})	91.93 ± 2.6	81.03 ± 4.1*

Note: Values were expressed as mean ± SD (n = 12); the values with an asterisk (*) in the row are statistically different from the control at p ≤ 0.05 (student's t-test); PVC = packed cell volume; Hb = hemoglobin; WBC = white blood cells and LYM = lymphocytes.

3.3. Effects of the EMR on Liver Function Enzymes and Proteins

Table 3 compares the effects of the EMR on the liver enzymes and proteins of the exposed rats with the control. The TP, AST, ALP, and ALT of the exposed rats were significantly increased ($P < 0.05$), while the ALB was significantly reduced. These findings agree with El-Bediwi *et al.* (2011) and Ghaedi *et al.* (2013) who observed elevated levels of AST and ALT as well as decreased levels of ALB in some rats exposed to mobile phone radiation. The increase in the liver enzymes of the rats in the present study could mean a sign of liver damage. According to El-Bediwi *et al.* (2011), the membrane of hepatocytes (liver cells) is highly permeable, so when the liver is injured, the liver enzymes are released into the bloodstream, raising the levels of the enzymes in the blood. The decrease in the ALB levels could indicate oxidative stress from the EMR, damaging the ALB molecules. According to Jbireal *et al.* (2018), EMR may generate reactive oxygen species, damaging cellular components such as proteins, lipids and DNA.

Table 3. Levels of the liver enzymes and proteins of the rats exposed to telecommunication mast EMR.

Parameter	Control	Exposed
TP (g L^{-1})	70.000 ± 0.58	95.00 ± 12.1*
ALB (g L^{-1})	40.67 ± 0.88	33.33 ± 0.88*
ALP (IU L^{-1})	21.00 ± 0.58	26.67 ± 3.18*
AST (IU L^{-1})	11.67 ± 0.88	21.02 ± 2.01*
ALT (IU L^{-1})	13.33 ± 0.67	19.00 ± 2.08*

Note: Values were expressed as mean ± SD (n = 12); the values along the same row with an asterisk (*) are statistically different from the control at $p \leq 0.05$ (student's t-test).

3.4. Effects of the EMR on Reproductive Performance

Table 4 reveals the effects of the EMR on the reproductive activities of the rats. While the control rats completed two reproductive cycles during the duration of the experiments, the exposed rats did one cycle. The number of offspring per birth and the offspring survival rates of the control rats were also higher than the exposed rats. These observations showed that the EMR reduced the reproductive function of the exposed rats and the survival rates of their offspring. The reduced offspring survival rates could be due to exposure during fetal development and after birth. The reduced reproductive function could result from the reduced activities of the rats, which could have reduced the mating frequency of the rats. The EMR could also induce sperm abnormalities in the exposed rats. According to Adah *et al.* (2018) and Kesan *et al.* (2018), EMR may induce oxidative stress, causing hormonal, sperm and testicular abnormalities. EMR exposure may also affect estrous cycle, pregnancy success, and fetal development (Gye and Park, 2012). An earlier study by Magras and Xenos (1997) observed a loss of reproductive function indicated by progressive decrease in the number of newborns in mice exposed to between 168 nW cm^{-2} and 1053 nW cm^{-2} RF-EMR.

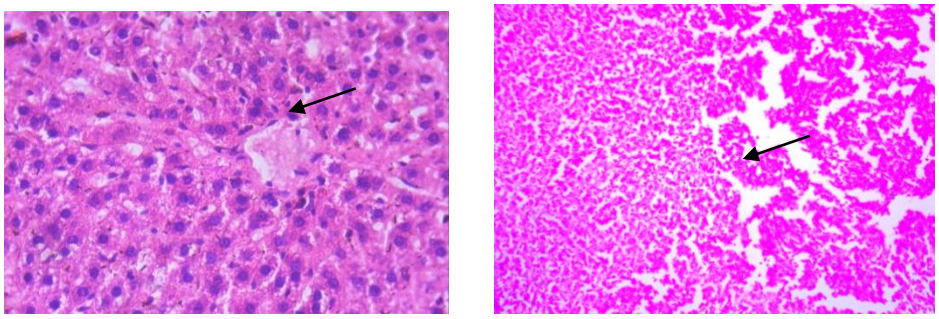
Table 4. Reproductive performance of the rats exposed to telecommunication mast EMR.

Group (n = 12)	No of reproductive cycles in 60 days	Offspring per birth	Offspring survival rate (%)
Control	2	12	90.00
Exposed	1	8	81.91

3.5. Histopathological Effects of the EMR

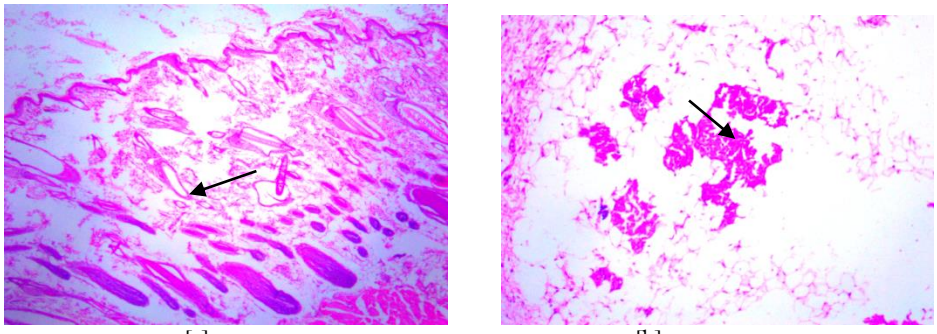
The effects of the EMR on the livers, skins, ovaries, kidneys, and lungs of the exposed rats are shown in Plates 1 to 5. While normal hepatocytes were seen in the livers of the control rats (Plate 1a), necrosis of the hepatocytes were observed in the livers of the exposed rats (Plate 1b). The skins of the control rats (Plate 2a) had mild thinning of the epidermis, while fat necrosis was observed in the epidermis of the exposed rats (Plate 2b). There were no histological changes in the ovaries of the control and exposed rats as both showed normal ovarian follicles (Plates 3 a and b). Plates 4 a and b also showed no abnormalities in the kidneys of the control and exposed rats as both groups had normal glomeruli and tubules. Similarly, normal alveolar spaces were observed in the lungs of the control and exposed rats (Plates 5 a and b).

The presence of necrosis in the livers and the skins of the exposed rats proved that the EMR was strong enough to induce biological effects, particularly tissue damage. Liver and kidney damage in rats exposed to 900 MHz EMR were reported by El-Bediwi *et al.* (2011) and Deniz *et al.* (2017). Akintonwa *et al.* (2009) also reported skin irritations among people living near telecommunication masts. EMR causes histopathology damage by inducing oxidative stress in the tissues of the exposed organisms, generating free radicals (Oktem *et al.*, 2005; Kıvrak *et al.*, 2017). The normal histology of the lungs, kidneys, and ovaries of the exposed rats in this study suggests that the livers and the skins are the most affected, or points of the first contact by the EMR. These claims are justifiable because the skin is the body's contact with the environment and the liver is the body's main detoxifier. The normal histology of the ovary further showed that the reduced reproductive function observed in the exposed rats could have been induced by other factors listed earlier.



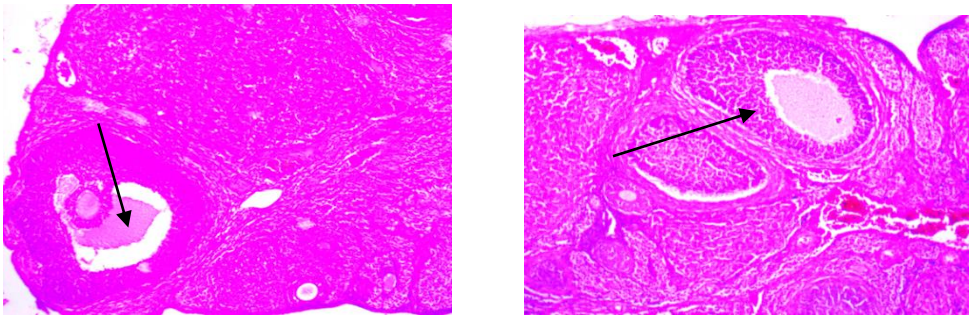
[a] **[b]**

Plate 1. Photomicrographs of the livers of the control rats (a) showing normal hepatocytes and exposed rats (b) showing necrosis of the hepatocytes (x 100).



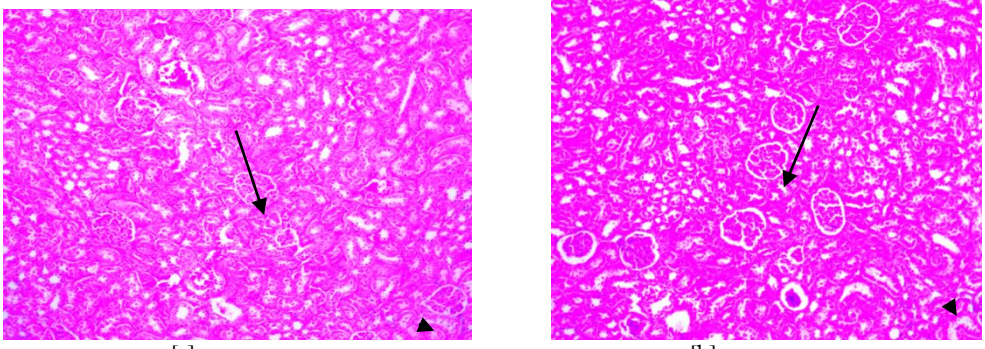
[a] [b]

Plate 2. Photomicrographs of the skin of the control rats (a) showing thinning of the epidermis and exposed rats (b) showing fat necrosis (x 100).



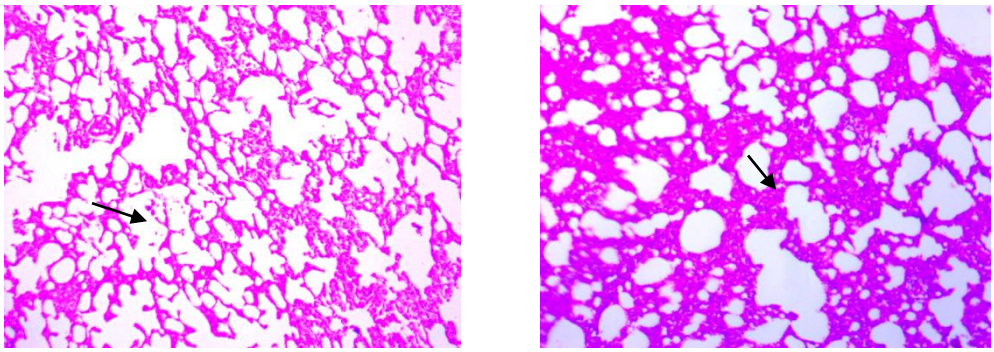
[a] [b]

Plate 3. Photomicrographs of the ovaries of the control (a) and exposed rats (b) showing normal ovarian follicle (x 100).



[a] [b]

Plate 4. Photomicrographs of the kidneys of the control (a) and exposed rats (b) showing normal glomeruli (long arrows) and tubules (short arrows) (x 100).



[a] [b]

Plate 5. Photomicrographs of the lungs of the control (a) and exposed rats (b) showing normal alveolar spaces (x 100).

4. Conclusion

The results of this study have established that exposure to telecommunication mast EMR can induce toxicity in biological systems. In particular, the EMR interfered with the functions of the selected health indices of the exposed rats, resulting in reduced reactivity. The exposed rats also weighed less than the control, indicating mitotic cell death or a loss of appetite consequent of the reduced activities. Similarly, the blood parameters as well as the liver enzymes and proteins of the exposed rats were altered, suggesting anemia and liver damage, respectively. The presence of necrosis in the livers and the skins of the exposed rats further proved the toxicity of the EMR. The exposed rats also showed reduced reproductive activities and offspring survival rates, which add to the body of evidence that EMR from the telecommunication mast was strong enough to cause harmful effects. Collectively, the findings of the study showed that exposure to telecommunication mast EMR can induce toxicity to cells and hence affect their functions. While we recommend further studies, it is advisable to site telecommunication masts away from dwelling places.

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