

Radiation Effects and Defects in Solids

Incorporating Plasma Science and Plasma Technology

ISSN: 1042-0150 (Print) 1029-4953 (Online) Journal homepage: www.tandfonline.com/journals/grad20

Effect of radiation emitted from mobile phone on innate immunity in mice

Yinhui Pei, Hui Gao, Mingzhu Zhang, Fangyuan Zhou, Yufang Zhu, Xiaoping Wang & Jian Sun

To cite this article: Yinhui Pei, Hui Gao, Mingzhu Zhang, Fangyuan Zhou, Yufang Zhu, Xiaoping Wang & Jian Sun (2024) Effect of radiation emitted from mobile phone on innate immunity in mice, Radiation Effects and Defects in Solids, 179:11-12, 1585-1596, DOI: [10.1080/10420150.2024.2352845](https://doi.org/10.1080/10420150.2024.2352845)

To link to this article: <https://doi.org/10.1080/10420150.2024.2352845>



Published online: 03 Jul 2024.



Submit your article to this journal [↗](#)



Article views: 140



View related articles [↗](#)



View Crossmark data [↗](#)



Citing articles: 1 View citing articles [↗](#)



Effect of radiation emitted from mobile phone on innate immunity in mice

Yinhui Pei^a, Hui Gao^b, Mingzhu Zhang^c, Fangyuan Zhou^d, Yufang Zhu^e,
Xiaoping Wang^d and Jian Sun^d

^aDepartment of Immunology, School of Elementary Medicine, North China University of Science and Technology, Tangshan, People's Republic of China; ^bDepartment of Clinical Medicine, Tangshan Vocational and Technical College, Tangshan, People's Republic of China; ^cDepartment of Surgery, North China University of Science and Technology Affiliated Hospital, Tangshan, People's Republic of China; ^dDepartment of Clinical Laboratory, North China University of Science and Technology Affiliated Hospital, Tangshan, People's Republic of China; ^eDepartment of Clinical Laboratory, Tangshan Hongci Hospital, Tangshan, People's Republic of China

ABSTRACT

This present study aims to explore the potential impact of cell phone radiation on innate immunity in mice. Ninety-six male BALB/C mice aged 2–3 weeks were randomly distributed into 4 groups as blank control, control, TD-SCDMA and LTE-Advanced respectively, with 32 mice in each group. Mice were designed to be exposed to cell phone radiation for 4–8 weeks. Eight mice in each group were taken out for measurement given exposure periods were 4, 6 and 8 weeks respectively. Cell biological technique was conducted to assess the chemotaxis of neutrophils, and a morphological method was performed for the detection of phagocytosis of neutrophil and macrophage, while microbiological means was carried out to test the relative activity of lysozyme in serum of mice. As a result, the chemotaxis ratio of neutrophils was with little statistical difference among the four groups given a shorter exposure period. However, the ratios in TD-SCDMA and LTE-Advanced groups were decreased significantly on the condition that the exposure period was more than 6 weeks. No statistical difference was observed among the four groups during the entire exposure period in terms of the chemotaxis index. Phagocytosis of the innate cells as neutrophil and macrophage showed little change in the two control groups during the whole experimental stages, while the percentage in the two treated groups decreased statistically, and this kind of reduction was prone to feature time dependence. The activities of lysozyme in TD-SCDMA and LTE-Advanced groups declined significantly, further to that, the impact was climbing paralleled with the prolonged duration. It could be deduced that radiation from cell phones could weaken innate immunity in experimental mice; moreover, this adverse effect was seemingly more severe as the radiation exposure continued.

ARTICLE HISTORY

Received 8 January 2024
Accepted 25 April 2024

KEYWORDS

Cell phone radiation; innate immunity; neutrophil; macrophage; lysozyme

1. Introduction

In recent years, along with the rapid development of advanced wireless communication techniques, cell phone subscribers are soaring. The application of mobile phones brought about great convenience in people's lives notwithstanding, concern over the adverse effect of electromagnetic radiation generated by such communication devices on health has been increasing. Over the past several decades, researchers around the world conducted many investigations on the impact of radiation on health; nevertheless, the results were different even contradictory for various designs in the studies. Earlier studies related to phone emission radiation have verified adverse effects on health. To the best of our knowledge, previous research work mainly focused on the central nervous system (1), endocrine system (2), cardiovascular system (3), reproductive capability (4), urinary (5), fetus (6), behavior (7) and carcinogenic effect (8). Up to now, the impact of radiofrequency electromagnetic field caused by mobile phones on innate immunity was rarely accessed; therefore, this present study tried to explore the correlation between radiation and innate immunity based on the analysis of data from experimental mice.

Immunity is classified into two types according to its characteristics as innate immunity and adaptive one. The former stands in the forefront to counter with antigens as exogenous pathogenic microorganisms and endogenous mutation tumor cells (9). There seems to be a general consensus that the damage of innate immunity could be conducive to the occurrence of infection and tumor in human beings. Given the life expectancies of mice and humans are 2 and 120 years respectively, 4–8 weeks of exposure to radiation in mice is equal to 12–24 years in humans. For this reason, this present experimental design on mice is expected to achieve a better mimic of chronic effects in long-term cell phone users. In this research work, the function of innate immune cells, as well as the activity of innate molecular was detected by various methods, ensued that, the impact of radiation on innate immunity was analyzed by the comparison of survey parameters in a different group.

2. Materials and methods

2.1. Animals and grouping

The study was carried out with 96 2–3 week-old male BALB/C mice (Beijing Vital River Laboratory Animal Technology CO., Ltd, Peking, China), with a weight range from 14.1 to 16.8 g. The experimental mice were placed at the Animal Laboratory Centre of North China Science and Technology University (animal room license, SYXK-Ji-2023-0038) under room temperature and a relative humidity of 55%. The mice were fed with balanced standard chow forage and drank tap water spontaneously in the course of the investigation. All of the 96 mice were acclimatized for 1 week and randomly allocated into 4 groups subsequently as follows: group A (blank control, $n = 24$), group B (control, $n = 24$), group C (Time Division synchronous CDMA, $n = 24$) and group D (Long Term Evolution-Advanced, $n = 24$). The 24 mice within one group were arranged in one plastic cage with a size of $320 \times 220 \times 160$ mm. The experimental procedures were made in accordance with the National Institutes of Health Guide for the Care and Use of Laboratory Animals and were also approved by the North China Science and Technology University Animal Ethical Committee. The four groups of mice were exposed to cell phone radiation in the following detailed manners respectively.

Group A (blank control group): Free from exposure.

Group B (control group): Exposed to mobile phones without a communication card.

Group C (TD-SCDMA group): Exposed to mobile phones with a Time Division synchronous CDMA communication card inserted.

Group D (LTE-advanced group): Exposed to mobile phones with a Long Term Evolution-Advanced communication card inserted.

The three mobile phones used in groups B, C and D were of the same type, HUAWEI PPA-AL20 mobile phone (Huawei Technologies CO., LTD. Shenzhen, China), and were located 2 cm beneath the center of the cages which were arranged at intervals of 5 m. The cell phones were switched on for 24 h and dialled once per hour from 8.00 am to 8.00 pm for a period of 4–8 weeks. All of the phones were adjusted to mute mode to ensure that the mice were only subjected to radiation rather than sound or vibration (10). The frequencies of phones with communication cards inserted in groups C and D were 1800 and 1900 MHz, respectively. The output effect of the TD-SCDMA mobile phone was 12 dBm when the phone was on standby, and it was 29 dBm when the phone was in the state of receiving the calling signal. While the corresponding values of LTE mobile phones were 10 and 27 dBm, respectively. The bottom area ($320 \times 220 \text{ mm}^2$) of the plastic cage was divided into 15 regions equally, and the electric field in the central part of each region was measured by PMM8053B (PMM, Italy). The average electric fields inside the cages of groups B, C, and D were 2.12, 9.84 and 9.83 V/m respectively, and the overall distribution of electric fields inside the mentioned three cages was presented on the basis of examination (Figure 1).

2.2. Detection of neutrophil chemotaxis

2.2.1. Chemotaxis ratio

Eight mice in each group were taken out for examination given radiation exposure periods were 4, 6 and 8 weeks, respectively. The middle of the right lower limb in each experimental mouse was disinfected with 75% alcohol (Tianjin Yongda Chemical Reagent CO., LTD. Tianjin, China). After that, a piece of the epidermis tissue with an area of 0.25 m^2 was cut off (the operation was gently conducted to ensure the hypodermis was unscathed). Five aseptic coverslips were stamped on the injured tissue of each mouse in the second hour after the operation. Wright's staining was performed after the slide was dried naturally at room temperature. Lastly, neutrophil in each slide was observed under Olympus microscope model CX23LED RFS1C (Olympus Guangzhou industry CO., Ltd. Guangzhou, China) with a magnification of 400, and the neutrophil chemotaxis ratio of the mouse was calculated according to the following formula:

$$\text{Ratio of neutrophil chemotaxis} = \text{number of neutrophil positive mice} / 8 \times 100\%$$

2.2.2. Chemotaxis index

one gram of agar was added to 99 ml of phosphate buffer saline (Beyotime Biotechnology Co., Peking, China), liquefied under a microwave oven with high power for 15 seconds, then 1 ml of calf serum was added to the above solution then it was cooled to 56°C . Following that the mixture was spread on the surface of sterile slides evenly (2.5 ml per slide). Then

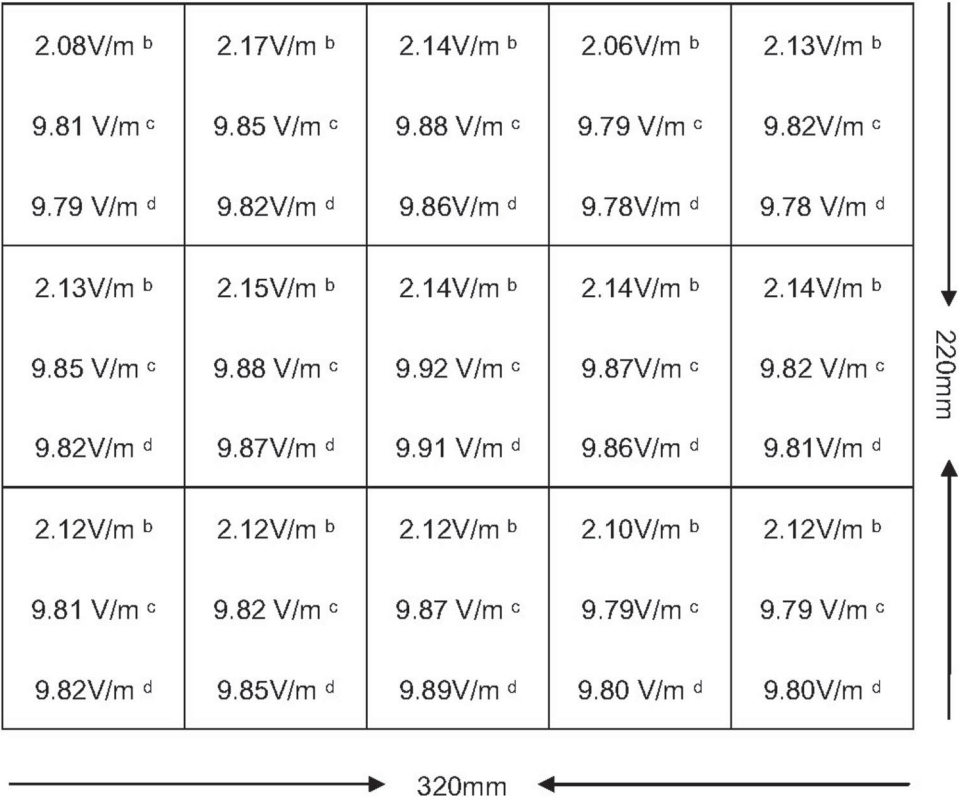


Figure 1. Maps of the electric field distributions in cages of the exposed mice. ^b Represents the measured value in the cage of the control group, ^c represents the measured value in the cage of the TD-SCDMA group and ^d represents the measured value in the cage of the LTE-Advanced group.

the slides were placed at 4°C for agar solidification. Finally, 4 pairs of holes with a diameter of 2.4 mm were drilled on the agar by a pinhole plotter in each slide, and the interval of 2 holes in each pair was 3.0 mm (Figure 2). A 25 µl blood sample collected from the caudal vein in each mouse was added to the left hole, while 25 µl of 100 ng/ml IL-8 (Beyotime Biotechnology Co., Peking, China) was added to the right side. Meanwhile, normal sodium served as control. All the slides were placed in a wet box and incubated at 37°C, under a 5% CO₂ atmosphere for 4 h. The agar was removed from slides, and the cell adhered to the slide was fixed with 4% formaldehyde for 5 min. Lastly, Wright's stain was applied and the migration distance of neutrophils was measured under a microscope, the procedure was repeated 5 times in each mouse. The distance of neutrophil migrated to IL-8 was taken as the length of chemotaxis, while that to normal sodium as the length of random migration. The migration index was calculated according to the following expression:

$$\text{Migration index} = \text{Length of chemotaxis} / \text{Length of random migration}$$

The average of five repeated measurements was regarded as the migration index of each mouse.

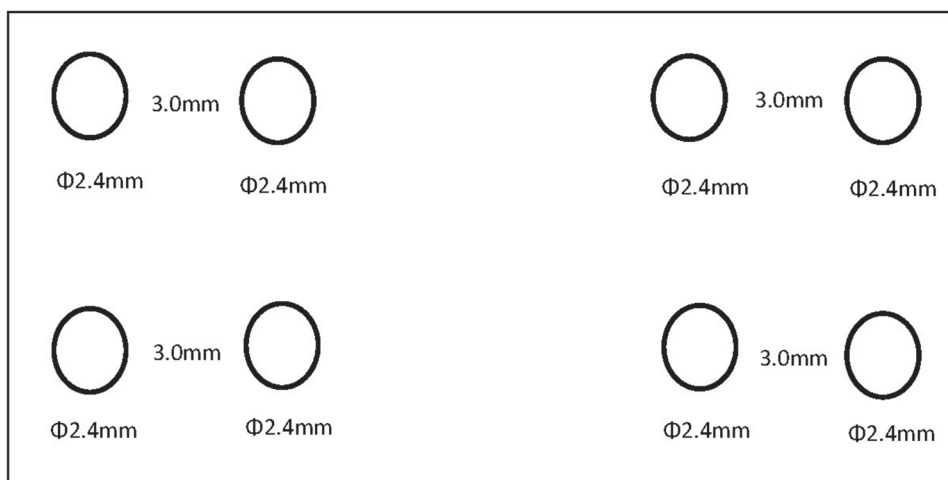


Figure 2. Diagram of the slide with drilled holes on agar for the examination of the chemotaxis index.

2.3. Assessment of phagocytosis of neutrophils in peripheral blood

Ten grams of peptone (Beyotime Biotechnology Co., Peking, China) and 5 g sodium chloride were added into 1 L distilled water respectively, sterilized at a temperature of 121°C for 25 min, and then adjusted PH to 7.4 with 0.1 mol/L sodium bicarbonate for further use. *Staphylococcus albus* (China General Microbiological Culture Collection Centre, Peking, China) was inoculated into the above-prepared peptone liquid medium and cultured at 37°C for 20 h, then the bacteria were adjusted to 5×10^6 /ml with normal sodium. Twenty-five microliters of blood sample collected from the caudal vein in each mouse was added into a sterilized concave slide containing 5 μ L of 0.125 IU/ μ L heparin sodium dripped into it previously. Later, 5 μ L of the *Staphylococcus albus* preparation was mixed into the sample, the slide was placed into a wet box and cultured at 37°C for 45 min. The smear was made on a clean slide, dried naturally and fixed by 4% formaldehyde for 5 min. In the end, Wright's stain was applied and the phagocytosis activity was observed under a microscope with a magnification of 1000, repeated 5 times in each mouse. The phagocytosis percentage was calculated according to the following formula:

$$\text{Phagocytosis percentage of neutrophils} = \frac{\text{Number of positive phagocytosis neutrophils}}{\text{Total neutrophils observed}} \times 100\%$$

The average of five measurements was regarded as the phagocytosis percentage of neutrophils of each mouse.

2.4. Examination of phagocytosis of macrophage in the abdominal cavity

Fifty gram of starch was added into 1 L broth slowly, and sterilized at 121°C for 25 min. One milliliter of the above mixture was injected into each of the experimental mice via the abdominal cavity 3 days before every examination point (the exposure period was 4, 6 and 8 weeks respectively). One milliliter of 1% chicken erythrocyte was injected into each mouse

via the abdominal cavity, and the abdominal cavity liquid was collected with a disposable syringe 30 min later. A smear was performed on a slide, and Wright's stain was applied after the procedure of fixation. Finally, the slide was observed under an Olympus microscope model CX23LED RFS1C (Olympus Guangzhou industry CO., Ltd. Guangzhou, China) with a magnification of 1000, repeated 5 times in each mouse. The percentage of macrophage phagocytosis was calculated according to the following expression:

$$\text{Percentage of macrophage phagocytosis} = \frac{\text{number of positive phagocytosis cells}}{\text{total number of observed cells}} \times 100\%$$

2.5. Test of lysozyme in the serum of mice

Micrococcus lysodeikticus (China General Microbiological Culture Collection Centre, Peking, China) was inoculated into the aforementioned prepared peptone liquid medium and cultured at 37°C for 20 h, then the bacteria were adjusted to 5×10^6 /mL with normal sodium. One milliliter of the above *M. lysodeikticus* suspension was mixed with 14 mL of 1% nutrient agar liquid at 56°C and then spread into a Petri dish with a diameter of 60 mm. Next, the dish was placed at 4°C for mixture solidification. Afterwards, 9 holes with a diameter of 2.4 mm were drilled on the agar by a pinhole plotter in each dish, and the holes were spaced 15 mm from each other. Fifty microliters of serum sample collected from a caudal vein in each mouse was added to the peripheral hole, while 50 μ L of standard lysozyme with a concentration of 100 μ g/mL (Beyotime Biotechnology Co., Peking, China) was added to the middle hole. All the dishes were placed in a wet box and incubated at 37°C, under a 5% CO₂ atmosphere for 24 h. The diameter of bacteria lysis around the hole was measured, repeated five times in each mouse, and the relative activity of lysozyme in the serum of the mouse was obtained according to the following expression:

$$\text{The relative activity of lysozyme} = \frac{\text{the diameter of bacteria lysis of serum}}{\text{the diameter of bacteria lysis of standard}} \times 100\%$$

2.6. Statistical analysis

The descriptive statistics in this research were presented as mean and standard deviation, and the statistical analysis was conducted by the Statistical Package for Social Sciences (SPSS) version 11.5 (SPSS Inc., Chicago, IL). The comparison of the ratio among the four groups was analyzed by the Chi-square test, while that of the other statistical parameters was conducted by one-way analysis of variance test and posts hoc multiple comparisons. The *P* value < 0.05 was considered statistically significant.

3. Results

3.1. Chemotaxis of neutrophil

To assess the possible impact of mobile phone radiation on the chemotaxis of neutrophils in mice, a cell biological technique was conducted to detect the chemotaxis ratio *in vivo*, while the agar gel method was operated for the examination of the chemotaxis index in

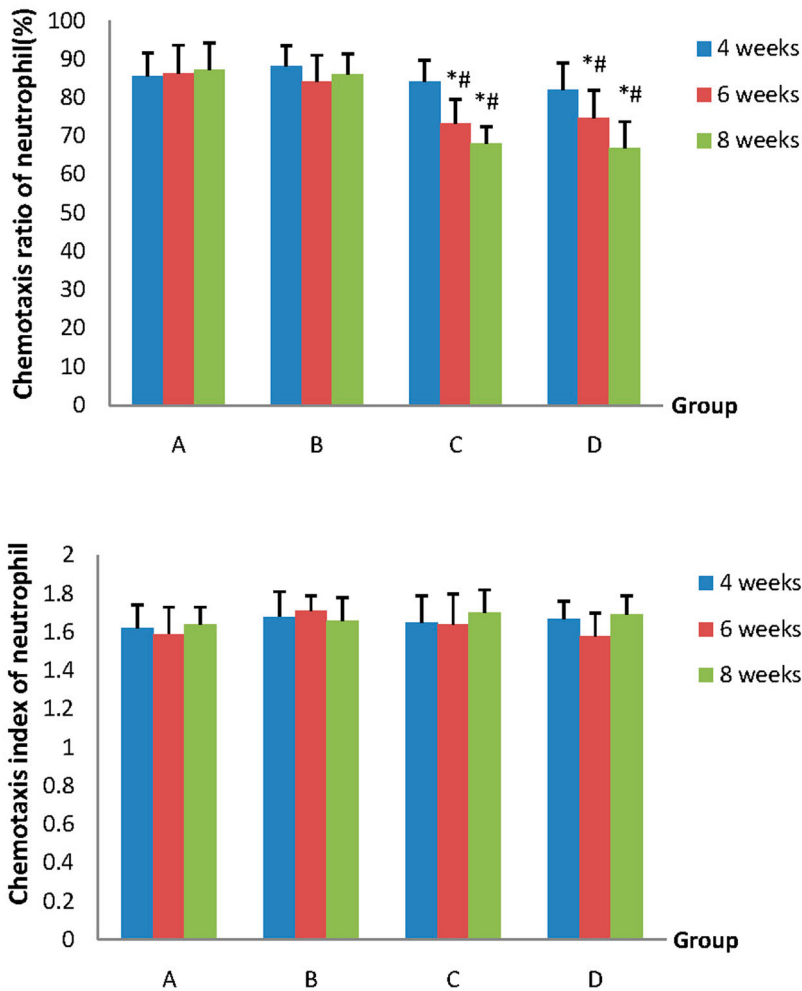


Figure 3. Chemotaxis of neutrophils in mice after exposure to mobile phone radiation. * Compared to Group A, $p < 0.05$; # Compared to Group B, $p < 0.05$. (A) blank group, (B) control group, (C) TD-SCDMA group and (D) LTE-Advanced group.

vitro after exposed to radiation for 4, 6 and 8 weeks, respectively. The results demonstrated that the chemotaxis ratio was with little statistical difference among the four groups given a shorter exposure period (4 weeks). Nonetheless, when compared to those in blank and control groups, the ratios in TD-SCDMA and LTE-Advanced groups were decreased significantly in pace with longer exposure periods (6 or 8 weeks). In terms of the chemotaxis index, no statistical differences were observed among the four groups at any one of the three exposure phases (Figure 3).

3.2. Phagocytosis of neutrophils in peripheral blood

A cell morphological procedure was carried out to evaluate the potential effect of electromagnetic radiation from cell phones on the phagocytosis of neutrophils in peripheral

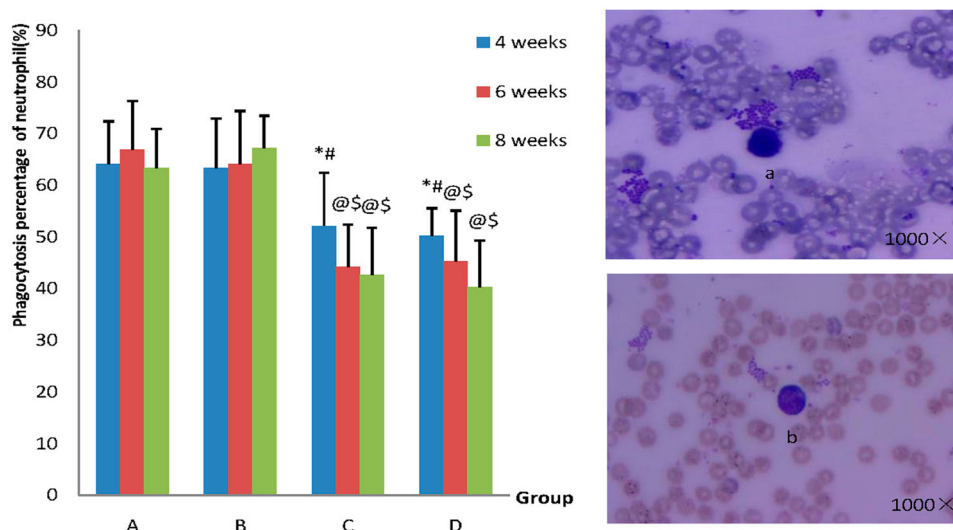


Figure 4. Percentage of neutrophil phagocytosis in mice after exposure to mobile phone radiation. (a) Expressed by negative phagocytosis neutrophil (*Staphylococcus albus* outside the cell), (b) expressed by positive phagocytosis neutrophil (*Staphylococcus albus* engulfed into the cell). * Compared to Group A, $p < 0.05$; # Compared to Group B, $p < 0.05$; @ Compared to Group A, $p < 0.01$; \$ Compared to Group B, $p < 0.01$. (A) blank group, (B) control group, (C) TD-SCDMA group and (D) LTE-Advanced group.

blood. The statistical analysis showcased no significant difference related to the percentage of phagocytosis at any exposure time in the two sham groups. The phagocytosis percentage points of TD-SCDMA and LTE-Advanced groups shrunk significantly compared to those of the blank and control groups at the 4th week ($p < 0.05$), what is more, they declined dramatically ($p < 0.01$) paralleled with the exposure time lasting to 6 or 8 weeks (Figure 4).

3.3. Phagocytosis of macrophage in the abdominal cavity

Innate immunity experimental means were performed to appraise the effect of cell radiation on phagocytosis of macrophage in the abdominal cavity of mice. The obtained result was very similar to that of neutrophils. In brief, the percentage of phagocytosis of macrophage showed little change in the 2 control groups during the whole experimental stages, while the percentage in the 2 treated groups decreased statistically compared to that in the control groups at the 4th week ($p < 0.05$), and the percentage in the exposure groups slipped significantly compared to that in the sham groups ($p < 0.01$) with time (Figure 5).

3.4. The relative activity of lysozyme

The microbiological technique was conducted to discover the impact of radiation from phones on the activity of lysozyme in the serum of mice. Statistical analysis based on the examination results demonstrated that there was no significant difference in the blank and control groups during the entire exposure phase. When compared to that in the sham groups, the activity of lysozyme in TD-SCDMA and LTE-Advanced groups

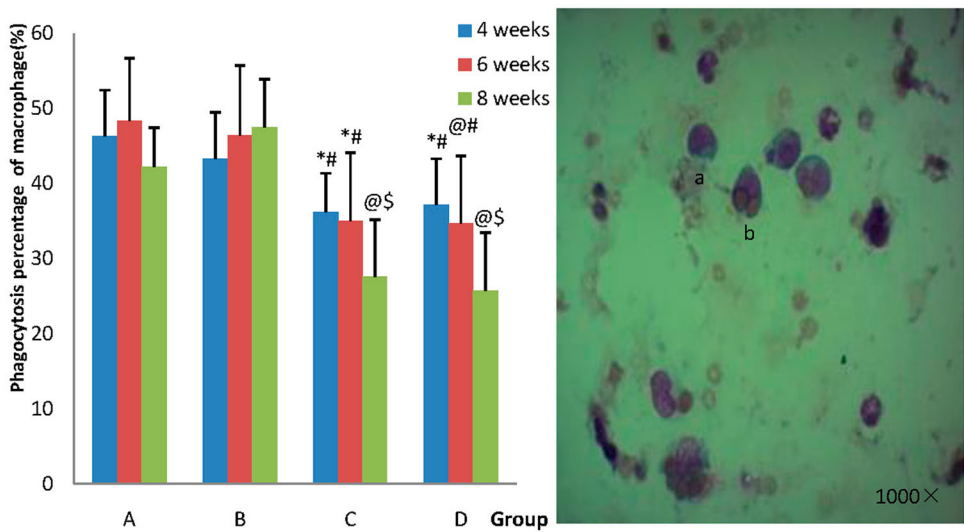


Figure 5. Percentage of macrophage phagocytosis in mice after exposure to mobile phone radiation. (a) Expressed by negative phagocytosis macrophage (no erythrocyte inside the cell), (b) expressed by positive phagocytosis macrophage (erythrocyte engulfed into the cell). * Compared to Group A, $p < 0.05$; # Compared to Group B, $p < 0.05$; @ Compared to Group A, $p < 0.01$; \$ Compared to Group B, $p < 0.01$. (A) blank group, (B) control group, (C) TD-SCDMA group and (D) LTE-Advanced group.

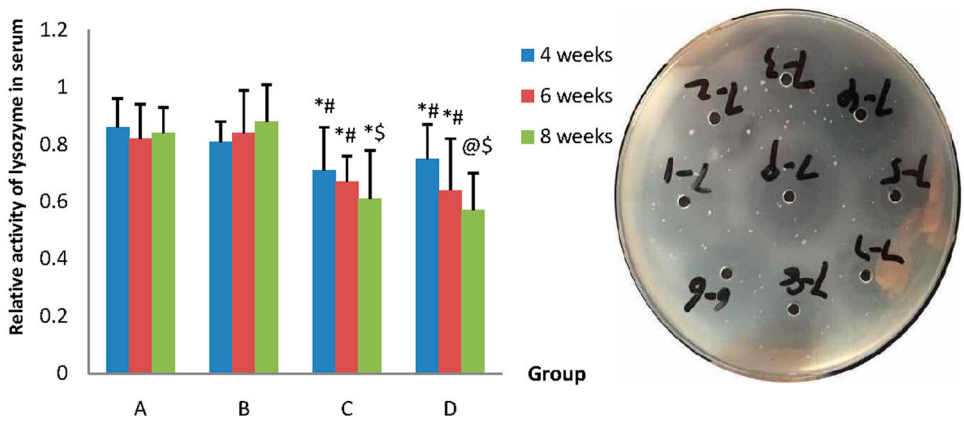


Figure 6. Relative activity of lysozyme in mice after exposure to mobile phone radiation. * Compared to Group A, $p < 0.05$; # Compared to Group B, $p < 0.05$; @ Compared to Group A, $p < 0.01$; \$ Compared to Group B, $p < 0.01$. (A) blank group, (B) control group, (C) TD-SCDMA group and (D) LTE-Advanced group.

declined significantly, further , the decline was remarkable along with the longer exposure time (Figure 6).

4. Discussion

Immunity refers to the process of recognition and clearness of antigens by the immune system, and it plays a vital role for the defence against microbial, such as bacteria, viruses

and fungi. According to the components involved in this process, immunity is classified into two types innate immunity and adaptive immunity respectively (11). Innate immunity, which is made up of immune cells and molecules, is in the front line to resist infection. With the help of pattern recognition receptors expressed on the surface of neutrophil and macrophages, it could give full play to phagocytosis (12). In terms of lysozyme, which is a very important immune molecular present in serum, tears, as well as many other secretions, might kill pathogenic organisms directly (13). In this paper, the function of neutrophil and macrophage, as well as the activity of lysozyme of mice after exposure to mobile phone radiation were studied to verify the potential effect of radiation on innate immunity.

Neutrophils, originating from bone marrow stem cells, migrate into peripheral blood or tissues after maturation under the instruction of various cytokines such as stem cell growth factor, granulocyte colony-stimulating colony factor and the others secreted by the bone marrow stromal cell (14). Neutrophils belong to polymorphic nuclei leukocytes, and it is the most populous cell accounting for 50–70% of leukocytes. Once pathogenic organisms enter the body, neutrophils would experience a process named chemotaxis. Firstly, neutrophils circulating in blood vessels might adhere to the vessel wall, and then migrate to the local infection with the help of chemokines secreted by the infected cell (15). The obtained results from this study discovered that although the chemotaxis index of neutrophils was unscathed after exposure to cell phone radiation, the chemotaxis ratio was weakened, so a conclusion might be drawn that mobile phones were prone to the damage of neutrophil migration rather than movement.

For neutrophils, the ultimate goal is to engulf and kill the invasion pathogen, not merely migrate to the location of infection. Once neutrophils contact with a pathogen, the membrane around the contact point will experience a process called internalization. Firstly, the membrane surrounding the pathogen will form phagocytotic vesicles, as a result, the invader could be engulfed into plasma. Secondly, neutrophils could bring phagocytosis into play (16). There are plenty of granules in the cytoplasm of neutrophils, such as azurophilic granules and specific granules which contain rich phagocytic and defensin, which are conducive to treat bacteria. In this way, the bacteria will get killed and the infection thus is terminated (17). The examination of neutrophil phagocytosis in mice demonstrated that the radiation might decrease the phagocytosis, and such an effect became more serious with longer exposure. A similar result was showcased in the previous research conducted by the author of this paper, in short, the phagocytosis of neutrophils was decreased after 6 weeks of exposure to cell phone radiation. In addition to this, apoptosis of neutrophils was detected to be enhanced (18), and it was speculated that such an enhancement might contribute to the reduction of chemotaxis and phagocytosis.

Macrophage, another important cell that mediates innate immunity, plays a vital role in dealing with large antigen particles. It is derived from monocytes and is named differently depending on the tissues, such as Kupfer cells in the liver, Osteoclast in bone, as well as macrophages in the connective tissue (19). Macrophages could phage antigens with the binding of pattern recognition receptors (20) (presenting on the surface of the membrane as a mannose-binding receptor, scavenger receptor, as well as Toll-like receptor) with pathogen-associated molecular pattern or damage-associated molecular pattern (presenting on the surface of the target cell) (21). Additionally, there are plenty of enzymes, such as peroxidase, acid phosphatase and alkaline phosphatase, which contribute to decompose the engulfed antigen (22). In this study, the macrophage was attracted to the abdominal

cavity of mice by non-bacterial inflammation via the injection of the aseptic starch broth. The advantage of chicken erythrocytes serving as the target is that phagocytosis could be observed easily for the distinctive blue-stained nucleus in chicken erythrocytes which is absent in any other kind of animal erythrocyte. The experiment on macrophages indicated that electromagnetic radiation from cell phones was likely to lower the phagocytosis of macrophages, and this kind of damage became more serious accompanied by the extended exposure time.

As a kind of nonspecific immunity substance, lysozyme is synthesized by many immune cells including macrophages, neutrophils and granulocytes, and secreted into serum, tear, saliva and other humor to contribute fully to its lysis. The mechanism of enzyme lysis is to inhibit the formation of the cross-linking bridge which is an important framework of peptidoglycan in the bacterial wall, and thus leads to cell wall defect. As a result, bacteria, especially Gram stain positive pathogen is damaged. The statistical analysis based on this experimental result related to lysozyme in the serum of mice showcased that cell phone radiation decreased the activity of lysozyme, and this kind of damage was seemingly seen to increase along with the longer exposure.

In summary, as evidenced by the research made in this paper, exposure to electromagnetic radiation emitted from mobile phones could result in the injury of innate immunity, more than that, the harm kept getting worse coinciding with the increase in exposure. To the best of our knowledge, the study on the correlation between radiation exposure and the adverse effect on innate immunity is the first of its kind ever openly accessed. Consequently, further researches should be continued to discover the possible mechanism of the impact at cell and molecule levels.

Acknowledgements

All authors contributed to this study. The conception and design were carried out by Yinhui Pei and Hui Gao. Animal experiments, detections and data collection were performed by Mingzhu Zhang, Fangyuan Zhou, Yufang Zhu, Xiaoping Wang and Jian Sun. Statistical analysis was conducted by Yinhui Pei. The manuscript was written by Yinhui Pei, and all authors read and approved it.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

- (1) Kumari, V.S.; Rohit, G.; Ramovtar, M.; Jay, P.N.; Sushil, K.J.; Paulraj, R. Effect of Mobile Phone Radiation on Oxidative Stress, Inflammatory Response, and Contextual Fear Memory in Wistar Rat. *Environ. Sci. Pollut. R.* **2020**, *27* (16), 19340–19351.
- (2) Noha, I.H.; Ayman, M.M.; Abeer, A.S. Decreased Level of Plasma Nesfatin-1 in Rats Exposed to Cell Phone Radiation is Correlated with Thyroid Dysfunction, Oxidative Stress, and Apoptosis. *Arch. Physiol. Biochem.* **2022**, *128* (6), 1486–1492.
- (3) Jamil, D.U.; Mikail, U.I.; Adesoji, A.F. Evaluation of Heart Rate Variability, Blood Pressure and Lipid Profile Alterations from Dual Transceiver Mobile Phone Radiation Exposure. *J. Basic Clin. Physiol. Pharmacol.* **2021**, *32* (5), 951–957.
- (4) Gang, Y.; Zhiming, B.; Chao, S.; Qing, C.; Gang, W.; Zeping, T.; Sixin, Y. Current Progress on the Effect of Mobile Phone Radiation on Sperm Quality: An Updated Systematic Review and Meta-Analysis of Human and Animal Studies. *Environ. Pollut.* **2021**, *282*, 116952.

- (5) Imam, H.; Tanjina, A.M.; Rafiqul, A.; Mohammad, R.I. Hematobiochemical and Histopathological Alterations of Kidney and Testis Due to Exposure of 4G Cell Phone Radiation in Mice. *Saudi J. Biol. Sci.* **2021**, *28*, 2933–2942.
- (6) Maryam, M.; Mohammad, A.K.; Fatemeh, A.; Mohammad, S.; Manuel, B. Challenges on the Effect of Cell Phone Radiation on Mammalian Embryos and Fetuses: A Review of the Literature. *Zygote* **2022**, *30*, 176–182.
- (7) Shima, H.; Firoozeh, G.; Farzad, E.; Saeed, G.; Afsaneh, B. Investigate the Relationship Between Cell-Phone Over-Use Scale with Depression, Anxiety and Stress among University Students. *BMC Psychiatry* **2022**, *22*, 755.
- (8) Hamideh, K.; Shirin, S.; Mahsa, M.; Niloofar, A. A Comparative Evaluation of the Genotoxic Effects of Mobile Phone Radiation Using Buccal Micronucleus Assay. *J Dent Shiraz Univ Med Sci* **2023**, *24* (1 Suppl), 118–124.
- (9) Bani, P.K.; Elizabeth, S. Innate Immunity. *Immunol Allergy Clin* **2021**, *41* (4), 535–541.
- (10) Pei, Y.H.; Gao, H.; Zhang, M.Z.; Wang, X.P.; Sun, J.; Zhou, F.Y.; Zhu, Y.F.; Yang, Y.J. Effect of Radiation Emitted from Mobile Phone on bone marrow haematopoietic stem cell in Mice. *Radiat Eff Defect S* **2023**, *178*. <https://doi.org/10.1080/10420150.2023.2222331>
- (11) Marta, C.; Kirill, S.; Stuart, H.F. Gut Microbial Regulation of Innate and Adaptive Immunity After Traumatic Brain Injury. *Neural. Regen. Res.* **2024**, *19* (2), 272–276.
- (12) Ruoyu, M.; Lei, D.; Chunming, W. Carbohydrates as Putative Pattern Recognition Receptor Agonists in Vaccine Development. *Trends Immunol.* **2023**, *44* (10), 845–857.
- (13) Pranay, A.M.; Ramakrishnan, G.; Jayati, R.D. Probing the Effects of Antimicrobial-Lysozyme Derivatization on Enzymatic Degradation of Poly(ϵ -Caprolactone) Film and Fiber. *Macromol. Biosci.* **2023**, *23* (12), e2300296.
- (14) Garth, L.B.; Alessandro, F.; Gerben, M.; Dhiren, F.P.; Arturo, Z. The Neutrophil. *Immunity* **2021**, *54* (7), 1377–1391.
- (15) Bjorn, P.; Maria, J.S. Neutrophil Chemotaxis. *Cell Tissue Res.* **2018**, *371* (3), 425–436.
- (16) Alexandra, Z.; Sophie, D.C.; Elodie, H.; Avin, B.; Abdul, I.B.; Oliver, N.; Julien, H. Distinct Timing of Neutrophil Spreading and Stiffening During Phagocytosis. *Biophys. J.* **2022**, *121* (8), 1381–1394.
- (17) Akishige, I.; Akihiro, K.; Ken, K.; Kanami, S.; Masashi, M. Presepsin Production in Monocyte/Macrophage-Mediated Phagocytosis of Neutrophil Extracellular Traps. *Sci. Rep.* **2022**, *12* (1), 5978.
- (18) Pei, Y.H.; Gao, H.; Li, L.; An, X.; Tian, Q.Y. Effect of Cell Phone Radiation on Neutrophil of Mice. *Int. J. Radiat. Biol.* **2019**, *95* (8), 1178–1184. <https://doi.org/10.1080/09553002.2019.1607605>
- (19) Venkata, S.R.; Stelios, P.; Gang, L.; Nazanin, Z.K.; Jennifer, S.; Joyce, T.; Sheila, D.; Yi, K.G.; Philip, M.H.; Simon, P.; Eric, F.M.; Ratko, D.; Peter, S.; Kian, F.C.; Ian, A.; James, H.; Maria, B.S. Macrophage Migration Inhibitory Factor Promotes Glucocorticoid Resistance of Neutrophilic Inflammation in a Murine Model of Severe Asthma. *Thorax* **2023**, *78* (7), 661–673.
- (20) Jack, G.; Jose, L.; Matthias, T. The Role of Macrophage Scavenger Receptor 1 (MSR1) in Inflammatory Disorders and Cancer. *Front Immuno* **2022**, *13*, 1012002.
- (21) Elizabeth, L.A.; Fela, M. Scavenger Receptor A1 Signaling Pathways Affecting Macrophage Functions in Innate and Adaptive Immunity. *Immuno Invest* **2022**, *51* (6), 1725–1755.
- (22) Chinaemerem, U.O.; Guillaume, E.D.; Alex, L.W.; Samuel, L.R.; Eva-Maria, F.; Gyorgy, F.; Olivier, D.C.; Clare, E.B.; Subhankar, M.; Siamon, G.; Robin, C.M. Toll-Like Receptor 4 and Macrophage Scavenger Receptor 1 Crosstalk Regulates Phagocytosis of a Fungal Pathogen. *Nat. Commun.* **2023**, *14* (1), 4895.