EFFECT OF ELECTROMAGNETIC FIELD ON BODY WEIGHT AND BLOOD INDICES IN ALBINO RATS AND THE THERAPEUTIC ACTION OF VITAMIN C OR E

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Abstract. The present work investigated the effect of electromagnetic field (EMF) radiated from mobile telephones base stations with frequency equals 900 MHz on body weight, blood indices and some liver enzymes of albino rats after exposing them to the electromagnetic field for 2 weeks. This work focuses on the therapeutic action of vitamin C or E against harmful effects induced by electromagnetic field. Results showed that electromagnetic field exposure caused a significant decrease in a growth rate. Significant increase in the following blood indices: the white blood cell count (*WBC*) recording 19.80% as compared to control level, mean corpuscular hemoglobin concentration (*MCHC*) and blood platelets count (*PLT*). And a significant decrease in red blood cell count (RBC), hemoglobin incidence (*HB*), hematocrit value, the mean corpuscular volume (*MCV*) and mean corpuscular hemoglobin concentration (*MCHC*). Serum aminotransferase (AST), alkaline aminotransferase (ALT) and alkaline phosphatase were significantly increased under electromagnetic field exposure. Signs of improvements in the body weight rate, the hematological parameters and the serum of liver enzymes were noticed during treatments with electromagnetic field in addition to vitamin C or E.

Key words: Electromagnetic field, albino rats, body weight, blood indices, therapeutic effect, vitamin C or E.

INTRODUCTION

Electromagnetic (EM) radiation is associated with numerous industrial, military, consumer and medical uses. The radio frequency (RF) portion of EM radiation (spectrum between 0.5 MHz–100 GHz) seems to affect certain organs and systems. Little is known about health risks from exposure to different sources of non-ionizing radiation. High exposure to non-ionizing radiation acutely affects

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sensitive organs, which mostly depends on radiations intensity, frequency, and exposure duration [7]. Mcree [12] and Roberts *et al*. [17] reported that several hematological variables are sensitive to RF/MW exposure, not only in animals, but also in humans. Preliminary investigation suggests that microwave exposure may affect the hematological parameters of exposed animals, and calls for further evaluation of specificity and biological significance of these biomarkers of exposure [1]. In a recent study [11], the authors examined immunological disorders in human and mice that had been exposed occupationally to environmental electromagnetic fields. Their results show that electromagnetic field caused a decrease of immunological parameters (total lymphocytes and CD4 counts) in both humans and mice. In a different study [4], results indicate that the applied GSM-like microwave exposure may induce slight, but statistically significant alterations in some hematological and endocrine parameters of male mice within the physiological range. Further investigations are required to establish the biological significance of these phenomena.

The present investigation aimed to study the effect on body weight, blood indices, and liver enzymes of albino rats after exposure to electromagnetic field and the therapeutic action of vitamin C or E against harmful exposure of electromagnetic field.

MATERIALS AND METHODS

Twenty-four adult male albino rats with weights as indicated in *Table* 1 were used throughout the study. The animals were kept in wood cages open from above at room temperature (27 °C) to avoid any metallic contamination or conduction under similar normal environmental conditions. The experiment was conducted at Islamic University biology laboratory. The use of these experimental animals was approved by Veterinary Service of the Municipality of Gaza and the ethics of the Islamic University of Gaza.

Fig. 1. The albino rats are placed in plastic cage exposed to 900 MHz electromagnetic fields from antenna placed 20 cm from the rats inside the cage.

Rats were equally divided into four groups as follows:

–The first group served as a control group.

–The second group was subjected to electromagnetic field.

–The third group was subjected to EMF and received vitamin C.

–The fourth group was subjected to EMF and received vitamin E.

A commercial balanced diet and water were supplied continuously and regularly to all animals all over the experimental period. Each vitamin was given orally in dose of 150 mg/kg/day all over the experimental period. The animals were exposed to electromagnetic field with constant power in the range from (1.4–4.7) mW/cm^2 (measured during the experiment using power meter) and electric field with the range (60–130) V/m. The whole body average specific absorption rate, 1.2 W/kg, was calculated from the relation SAR = Power/density.

The treated animals were subjected to split dose of electromagnetic fields where rats were exposed to the field for eight hours followed with eight hours without being exposed to the fields sequentially for two weeks. The electromagnetic field applied was generated by using an antenna installed inside the cage and at 20cm from the rats as shown in Fig. 1. The antenna received the signal from mobile base station at the area of Islamic University of Gaza. The mobile system used in Gaza is GSM (Global system for mobile) which frequency equals 900 MHz. The animals were kept in a wood box. Then a horizontal electromagnetic induction was applied to whole body of the animal.

At the end of the experiment, animals from both control and experimental groups were decapitated. After wards, the blood samples were collected between 6–7 mL from each rat depending on the rat body weight. For the hematological tests, approximately 2–3 mL of blood sample were received at a tube containing dipotassium ethylene diaminetetra acetate (EDTA). In addition, about 2–3 mL of blood was collected into a centrifuge tube without any anticoagulant for the biochemical tests.

MORPHOLOGICAL STUDIES

Animals were individually weighed weekly in order to detect any changes in their body weights. A sensitive balance was used and weights were recorded to the nearest gram. About 2–3 mL of blood sample depending on the rat weight were received at a tube containing dipotassium ethylene diaminetetra acetate (EDTA).

HEMATOLOGICAL PARAMETERS

Determination of hematological parameter was carried out using 18 automated parameter hematology analyzer, ABX Micros 60 from Horiba ABX, France. No significant difference was found in hematological parameters determined either by routine clinic methods or by instrumental methods.

Blood cell counts

The total red blood cell (RBC) counts are measured in millions per cubic millimeter (mil/μL) of blood. White blood cell (*WBC*) counts are measured in thousands per cubic milliliter (k/μL) of blood and blood platelet (*PLT*) counts are measured in thousands per cubic millimeter (k/μL) of blood. The blood is drawn in a test tube containing an anticoagulant (EDTA, sometimes citrate) to stop it from clotting as recommended by Dacie and Lewis (2006) [10]. They are analyzed using the 18 automated parameter hematology analyzer.

Packed cell volume (hematocrit value)

Hematocrit values were determined by allowing the blood to flow into capillary heparinized tubes from decapitated rats then centrifuged in a hematocrit centrifuge at 1000g for 5 min.

MCV, MCH, MCHC

The volume of the average erythrocyte, mean corpuscular volume (*MCV*), was calculated from RBCs count and hemoglobin count (see next section) as follows [2]:

Mean corpuscular volume = (hematocrit/Red blood cells count in millions) × 10 fL.

Mean corpuscular hemoglobin (*MCH*) was calculated from RBCs count and hemoglobin as follows:

MCH = (Hemoglobin concentration / Red blood cell count in millions) × 10 pg.

While the mean corpuscular hemoglobin concentration (*MCHC*) and the percentage of hemoglobin counts of packed cell volume of whole blood were calculated from hemoglobin and hematocrit as follows:

MCHC = (Hemoglobin content/Hematocrit) g/dL.

Hemoglobin content

Blood hemoglobin was determined using the Sigma reagent kits (Sigma Chemical Co., St. Louis, MO, USA) following their manual instruction. Hemoglobin was converted into cynmethemoglobin by potassium ferricyanid and cyanid. Cyanmethemoglobin was measured colorimetrically where the intensity of color is proportional to the hemoglobin concentration. Twenty micro liters of the blood were added to 5 milliliters of diluted Drabkins solution. Standard was prepared by adding 20 micro liters of redistilled water to 5 milliliters of cyanmethemoglobin. The colors of the sample and standard were measured using Perkin-Elmer Lambda 1A UV-VIS spectrophotometer at 540 nm, made in Taiwan.

BIOCHEMICAL PARAMETER

For the biochemical tests, about 2–3 mL of blood sample depending on the rat weight was collected into a centrifuge tube without any anticoagulant. The centrifuge tube was left for about 15 min to allow blood coagulation. Clear serum samples were then separated by centrifugation at 1000g for 20 min. Clear serum samples were separated in glass tubes, labeled and stored in deep freezer for different biochemical analysis for different biochemical assays. However, determination of enzyme activities was carried out on fresh serum samples.

Serum aspartate aminotransferase (AST) is an enzyme belonging to the class of transferases. It is commonly referred to as a transamilase and is involved in the transfer of an amino group between aspartate and aketo acids. AST activity is measured by using optimized ultraviolet-test according to International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) [19].

Serum alanine aminotransferase (ALT) is a transferase with enzymatic activity similar to AST. Specifically, it catalyzes the transfer of an amino group from alanine to aketoglutarate with the formation of glutamate and pyruvate. ALT activity is measured by using optimized ultraviolet-test according to IFCC [19, 13].

Serum alkaline phosphatase (ALP) belongs to a group of enzymes that catalyze the hydrolysis of various phosphomonoesters at an alkaline pH. Consequently, ALP is a nonspecific enzyme capable of reacting with many different substrates. Specifically, ALP functions to liberate inorganic phosphate from an organic phosphate ester with the concomitant production of an alcohol. ALP activities are measured by kinetic photometric test, according to International Federation of Clinical Chemistry and Laboratory Medicine [3].

DATA ANALYSIS

Data were analyzed using SPSS program (statistical package for social sciences Inc. Chicago, Illinois). Means were compared by independent-sample t-test. A difference was considered significant at probability $P \leq 0.05$.

RESULTS

Table 1 demonstrates the average weekly body weight of control and experimental groups. It is obvious that control animals showed a progressive increase in body weight with the lapse of time. Gradual increase in the body weight of rats treated with electromagnetic field in addition to vitamin C or E has been noticed.

Table 2 showed the different effects on the hematological parameter after exposure of rats to an electromagnetic field alone and after exposure to an electromagnetic field accompanied with the treatment by vitamin C and E. Data

showed that the electromagnetic field exposure caused a general elevation in the total leukocytic count and lymphocyte percentage recording 19.8% and 25.6% respectively as compared to the controlled level. However, electromagnetic field exposure and treatment by vitamin C caused an increase in the total leukocytic count and lymphocyte percentage by 7.8% and 10.2% respectively as compared to the controlled group.

Table 1

Effects of electromagnetic field exposure and treatment of vitamin C or E on the body weight of albino rats

Experimental period	Body weight (g) of albino rats			
	Control $N = 6$	EMF $N = 6$	EMF + vitamin C $N = 6$	EMF + vitamin E $N = 6$
The beginning of the experiment	120±0.15	122±0.20	121±0.19	124±0.18
1 week	124.67±0.15	108.5±0.11	129.67±0.17	131.84±0.13
%change		–13%	4%	5.75%
P		<0.05	> 0.05	> 0.05
2 week	140.11±0.19	114.50±0.16	151.28±0.14	158.61±0.17
%change		–18.3%	8%	13.2%
P		<0.01	>0.05	<0.05

All values expressed as mean ± S.E.; non significant differences at $P > 0.05$; significant differences at $P \leq 0.05$; highly significant differences at $P \leq 0.01$.

On the other hand, the red blood cell (RBC) count showed a significant decrease upon electromagnetic field exposure recording 12.2% reduction compared to the control level. However, after rats exposed to electromagnetic field and treatment by vitamin C or vitamin E, the RBC increased by 6.9% and 8.9% respectively as compared to the control level. In general, the effect of electromagnetic field on hemoglobin and hematocrit value (*HB*) significantly decreased to 14.9% and 20.8% when compared to the control level respectively. Mean corpuscular volume (*MCV*) and mean corpuscular hemoglobin (*MCH*) decreased in response to electromagnetic field exposure recording 9.8% and 3.0% respectively compared to the control level. However, after treatment with vitamin C, the values of *MCV* and *MCH* decreased by 17.2% and 15.3% respectively compared to the control level (Table 2). Electromagnetic field exposure caused generally an increase in the mean corpuscular hemoglobin concentration (*MCHC*) with a value of 7.51% compared to the control level. However, *MCHC* decreased by 2.3% compared to control group after exposure to electromagnetic field and treatment with vitamin C.

Table 2

Effect of electromagnetic field exposure on blood indices in albino rats and therapeutic action of vitamin C or E

Parameter	Control $N = 6$	EMF $N = 6$	EMF + vitamin C $N = 6$	EMF + vitamin E $N = 6$
Monocytes (10^3/mm^3) %Change	13.50±0.05	10.4±0.25 –23.0	12.50±0.20 –7.4	16.8±0.27 24.4
WBC (10^3cell/μL) %Change *P*	5.10±0.13	6.11±0.11 19.8 <0.01	5.50±0.10 7.8 > 0.05	5.80±0.13 13.7 <0.05
Lymphocytes %Change *P*	66.5±1.15	83.5±1.50 25.6 <0.001	73.30±1.45 10.2 0.05 <	56.1 –15.10 <0.001
RBC (10^6 cell/μL) %Change *P*	6.98±0.9	6.13±0.12 –12.2 <0.05	7.46±0.8 6.9 > 0.05	7.60±0.15 8.9 > 0.05
HB (g/dL) %Change *P*	14.8±0.40	12.6±0.50 –14.9 <0.05	13.4±0.30 –9.5 > 0.05	12.30±0.20 –16.9 <0.05
Hematocrit %Change *P*	45.20±1.50	35.8±1.33 –20.80 <0.001	40±1.45 –11.5 <0.05	39.6±1.10 –12.39 <0.05
MCV (fL) %Change *P*	64.76±0.2	58.40±0.3 –9.82 > 0.05	53.62±0.41 –17.2 <0. 01	52.11±0.35 –19.5 <0. 01
MCH (pg) %Change *P*	21.20±0.15	20.56±0.18 –3.0 > 0.05	17.96±0.20 –15.3 <0. 01	16.18±0.25 –23.7 <0. 01
MCHC (g/dL) %Change *P*	32.74±0.11	35.20±0.16 7.5 > 0.05	33.5±0.10 2.3 > 0.05	31.06+±0.17 –5.1 > 0.05
Platelets (10^3/μL) %Change *P*	375.16±2.50	627±2.61 67.1 <0.001	417±4.30 11.2 <0.05	569.11±5.18 51.7 <0.001

All values expressed as mean ± S.E.; non significant differences at $P > 0.05$; significant differences at $P \leq 0.05$; highly significant differences at $P \leq 0.01$.

Electromagnetic field exposure caused a significant increase in blood platelet (*PLT*) count with a value of 67.14% compared to the control level. However, after exposing the rats to the electromagnetic field and treating them with vitamin C or E, the *PLT* count increased by 11.15% and 51.70% respectively compared with control level.

Table 3 shows the effect of electromagnetic and treatment of vitamin C and E on liver enzymes. Activities of serum aminotransferase (AST), alaninaminotransferase (ALT) and alkaline phosphatase (ALP) were increased significantly following electromagnetic fields exposure to rats for two weeks.

However, these activities were reduced after the treatment by vitamin C or vitamin E when compared to rats exposed to electromagnetic fields only. However, the AST, ALT and ALP enzyme activities remained high in all treatment groups as compared to control group. Vitamin E was more effective in reducing the elevation of ALT, AST, and ALP.

Table 3

Serum ALT, AST, and ALP activities in albino rats after exposure of electromagnetic field and the therapeutic action of vitamin C or E for 2 weeks

Parameter	Control $N = 6$	EMF $N = 6$	EMF + vitamin C $N = 6$	EMF + vitamin E $N = 6$
ALT (U/mL)	35.91 ± 1.40	61.30+1.75**	53.69 ±1.80*	48.15 ±1.78*
% change		70.7%	49.5%	34.1%
P		<0.001	<0. 001	<0. 001
AST (GPT) (U/mL)	39.11 ± 1.44	56.7±1.35*	48.16 ±1.36*	45.90 ±2.50*
% change		45%	23.1%	17.4%
P		<0. 001	<0.001	<0. 01
Alkalinephos (U/mL)	62.8 ± 1.80	73.33±1.76*	68.10 ± 1.70	63.76 ± 1.54
% change		16.8%	8.4%	1.5%
P		<0. 01	> 0.05	> 0.05

All values expressed as mean ± S.E.; non significant differences at $P > 0.05$; significant differences at $P \leq 0.05$; highly significant differences at $P \leq 0.01$.

DISCUSSION

In our experiment, we noticed the decrease in the body weight following electromagnetic field exposure which agrees with the results of Wilson *et al*. [21]. Gerardi *et al*. [6] observed that the body weight changes when rats exposed for long-term exposure to electromagnetic fields with a well-defined frequency. However, they have noticed an increase in the body weight. However, this does not agree with the results obtained by González-Riola *et al*. [9] in which the authors indicate that there is no significant difference in the initial and final body weight.

The exposure of rats to electromagnetic field alone exhibited a general increase in *WBC*s (leukocytosis), *MCHC* and platlet count of albino rats. Leukocytosis was manifested by lymphocytosis. The increase in lymphocytes may be due to the harmful action of electromagnetic field exposure that stimulates the haemopoietic system to release more lymphocytes causing an increase in their number in the blood stream. It has been shown [16] that long-term intermittent exposure to electromagnetic field (RF) can enhance the probability that mice carrying a lymphomagenic oncogene will develop lymphomas. Significant decline was recorded related to RBCs, *HB*, and HT, *MCV* and *MCH* compared to the control group.

Our findings agree with previous studies done by Forgács [5] and Roberts *et al*. [17] in which results show that several haematological variables are sensitive to RF/MW exposure. Those included white blood cell count, differential white blood cell count, platelet levels, red blood cell count, mitotic index of haematopoietic stem-cells, as well as haematocrit, haemoglobin and bone marrow megakaryocytes. According to these authors, changes in the above parameters repeatedly occurred after either short- or long-term MW/RF exposures, regardless of the power density of the electromagnetic field. In contrast, Rotkovska *et al*. [18] found no differences in the total erythrocyte count between irradiated and nonirradiated mice, although she reported a statistically significant decrease in total leukocytes in the exposed animals. Her analyses of blood smears showed a lower percentage of granulocytes in irradiated mice than in controls. The experimental group was exposed to 34 GHz MW radiation with a power density of 20 $\mu W/cm^2$. Goldsmith [8] described changes in red and white blood cell count in rats exposed to 13 mW/cm^2 power density MW fields.

Serum transaminases (AST& ALT) and alkaline phosphatase (ALP) exhibited significant increase in electromagnetic field treated rats compared to the control group in agreement with a study done by Moussa [14]. Both alanine aminotransferase (ALT) and aspartate aminotransferase (AST), as reported, are specific liver enzymes that increase in hepatic diseases and toxic damage of liver cells [15].

Glucocorticoids also enhance transamination processes. Increased aspartate aminotransferase levels can however occur in connection with damages of heart or skeletal muscle as well as of liver parenchyma [20].

The activities of these enzymes were reduced after the treatment by vitamin C or E when compared to the control group. The electromagnetic field which induced oxidative stress has lowered.

CONCLUSIONS

The work of this paper aimed to study the effect of electromagnetic field with 900 MHz frequency generated from GSM antenna on the body weight, blood indices and some liver enzymes of albino rats. In this work, we also investigate the therapeutic effect of vitamin C or E on the albino rats while exposing to electromagnetic radiations.

Our results indicated that the weight, the blood parameters and the serum activities (ALT, AST, and ALP) of albino rats have been affected by electromagnetic field exposure. However, most of these changes showed signs of improvements with vitamin C or E treatments compared to electromagnetic field exposure alone.

REFERENCES

1. BONHOMME-FAIVRE, L., S. MARION, F. FORESTIER, R. SANTINI, H. AUCLAIR, Effects of electromagnetic fields on the immune systems of occupationally exposed humans and mice, *Archives of Environmental Health: An International Journal*, 2003, **58**, 712–717.
2. CHEESBROUGH, M., *District Laboratory Practice in Tropical Countries.* Part II., Cambridge University, UK, 2001.
3. ERASLAN, G., A. BILGILI, D. ESSIZ, M. AKDOGAN, F. SAHINDOKUYUCU, The effects of deltamethrin on some serum biochemical parameters in mice, *Pesticide Biochemistry and Physiology,* 2007, **87**, 123–130.
4. FORGÁCS, Z., G. KUBINYI, G. SINAY, J. BAKOS, A. HUDÁK, A. SURJÁN, C. RÉVÉSZ, G. THURÓCZY, Effects of 1800 MHz GSM-like exposure on the gonadal function and hematological parameters of male mice (in Hungarian), *Magy. Onkol*., 2005, 49, 149–151.
5. FORGÁCS, Z., Z. SOMOSYB, G. KUBINYIB, J. BAKOSB, A. HUDÁKC, A. SURJÁNA, G. THURÓCZYB,. Effect of whole-body 1800 MHz GSM-like microwave exposure on testicular steroidogenesis and histology in mice, *Reproductive Toxicology*, 2006, **22**, 111–117.
6. GERARDI, G., A. DE NINNO, M. PROSDOCIMI, V. FERRARI, F. BARBARO, S. MAZZARIOL, D. BERNARDINI, G. TALPO, Effects of electromagnetic fields of low frequency and low intensity on rat metabolism, *BioMagnetic Research and Technology*, 2008, **6**, 1–8.
7. GOLDONI, J., Non-ionizing radiation protection in medicine, *Arh. Hig. Rada Toksikol.*, 1994, **45**, 175–187.
8. GOLDSMITH, J.R., Epidemiologic evidence relevant to radar (microwave) effects, *Environ. Health Persp*., 1997, **105**, 1579–1587.
9. GONZÁLEZ-RIOLA, J., J.A. PAMIES, E.R. HERNÁNDEZ, M. REVILLA, C. SECO, L.F. VILLA, H. RICO, Influence of electromagnetic fields on bone mass and growth in developing rats: A morphometric, densitometric, and histomorphometric study, *Calcif. Tissue Int.*, 1997, **60**, 533–537.
10. LEWIS, S.M., B.J. BAIN, I. BATES, *Dacie and Lewis Practical Haematology*, Churchill Livingstone, USA, 2006.
11. MATAUŠIĆ-PIŠL, M., I. TROŠIĆ, Z. PIŠL, Ž. RADALJ, Whole body microwave exposure and peripheral blood of rats: pilot study, *Veterinarski Arhiv.*, 2000, **70**, 279–287.
12. MCREE, D.I., Review of Soviet/Eastern European research on health aspects of microwave radiation, *Bull. N.Y. Acad. Med*., 1979, 55, 1133–1151.
13. MOSS, D.W., A.R. HENDERSON, Clinical enzymology, In: Burtis CA, Ashwood ER, eds., *Tietz Textbook of Clinical Chemistry*, WB Saunders Co, Philadelphia, 1999, pp. 617–721.
14. MOUSSA, S.A., Oxidative stress in rats exposed to microwave radiation, *Romanian J. Biophys.*, 2009, **19**, 149–158.
15. PASHOVKINA, M.S., I.G. AKOEV, The liver enzymes which increase in hepatic diseases and toxic damage of liver cells, *Biol. Radioecol*., 2001, **41**, 62–68.
16. REPACHOLI, M.H., A. BASTEN, V. GEBSKI, D. NOONAN, J. FINNIE, A.W. HARRIS, Lymphomas in Eμ-Pim1 transgenic mice exposed to pulsed 900 MHz electromagnetic fields, *Radiation Research*, 1997, **147**, 631–640.
17. ROBERTS, N.J. Jr., S.M. MICHAELSON, S-T. LU, The biological effects of radiofrequency radiation: a critical review and recommendations, *Int. J. Radiat. Biol*. 1986, **50**, 379–420.
18. ROTKOVSKA, D., J. MOE, J. KAUTKSA, A. BARTONEKOVA, J. KEPRTOVA, M. HOFER, Evaluation of the biological effects of police radar Ramer 7F, *Environ. Health Persp*., 1993, **101**, 134–136.
19. THOMAS, L., Alanine aminotransferase (ALT), Aspartate aminotransferase (AST), In: L. Thomas, ed., *Clinical Laboratory Diagnostics*, Frankfurt: TH-Books Verlagsgesellschaft, 1998, pp. 55–65.
20. VOZAROVA, B., N. STEFAN, S.R. LINDSAY, A. SAREMI, E.R. PRATLEY, C. BOGARDUS, A.P. TATARNNI, High alanine aminotransferase is associated with decreased hepatic insulin sensitivity and predicts the development of type 2 diabetes, *Diabetes*, 2002, **51**, 1889–1895.
21. WILSON, B. W., K.S. MATT, J.E .MORRIS, L.B. SASSER, D.L. MILLER, E.A. LARRY, Effect of 60 Hz magnetic field exposure on the pineal and hypothalamic-pituitary-gonadal axis in the Siberian hamster, *Bioelectromagnetics*, 1999, **20**, 224–232.