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Effect Exposure of Mobile Radiation on Human Red Blood Cell in Vitro

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ABSTRACT
Objective: Wireless technologies are expanding rapidly, leading to a marked increase in human exposure to electromagnetic radiation (EMR), mainly in the microwave frequency band emitted by mobile phones. This study aimed to investigate the effect of cell phone–generated microwave radiation on human red blood cells (RBCs) in vitro.
Methods: Blood samples were collected from healthy volunteers and exposed to microwaves emitted from mobile phones at a distance of 1 cm for durations of 1, 5, and 20 minutes. Both computerized and manual hematological parameters were analyzed, including hemoglobin (Hb), hematocrit (Hct), RBC count, mean corpuscular hemoglobin (MCH), and mean corpuscular hemoglobin concentration (MCHC), aggregation, deformability, and osmotic fragility.
Results: A significant reduction in Hb concentration was observed after 20 minutes of exposure, along with a significant decrease in RBC count after 1 minute. The flow rate increased markedly, while aggregation and deformability parameters indicated alterations in the RBC membrane.
Conclusion: The findings suggest that non-thermal microwave exposure can affect RBC morphology and function, likely through modifications in membrane integrity and surface charge, which may have implications for blood rheology under prolonged EMR exposure.
Keywords: electromagnetic radiation, microwave, red blood cells, hemoglobin, non-thermal effects.

INTRODUCTION
In addition, the increasing number of mobile phones, wireless communication systems have brought a tremendous increase in human exposure to EMR (electromagnetic radiation). Mobile phones and base stations produce EMR, and billions of people worldwide are still exposed to it (1– 3). These devices are regarded as an emerging biological risk, and further raise alarm about their probable impacts on human health (4, 5). Mobile phones work in the microwave frequency band, which is usually 900–1800 MHz for GSM systems and higher frequencies for more modern communication technologies including 4G and 5G (2, 3).

Their antennas are usually positioned close to the head during use; therefore, a significant portion of the emitted radiation directly interacts with biological tissues. It has been demonstrated that most of the radiation emitted toward the head is absorbed in the hemisphere on the side where the phone is used [(6)]. Radiation from base stations also contributes to continuous low-level exposure in the surrounding environment, although exposure intensity decreases with increasing distance [(7)].

Microwave or radiofrequency (RF) radiation, being non-ionizing, primarily causes tissue heating at high intensities; however, recent studies are investigating possible non-thermal biological effects at lower exposure levels. Recent evidence indicates DNA damage in human blood mononuclear cells after mobile phone–specific RF exposure [(2)], changes in gene expression in chick embryo models [(7)], and organ function alterations in experimental animals exposed to 4G radiation [(8)]. These findings support the ongoing debate regarding the biological implications of long-term, low-level RF exposure and its potential health significance [(5)].

Microwaves Radiation

Microwaves represent a form of non-ionizing electromagnetic radiation, characterized by frequencies ranging from 0.3 to 300 GHz and wavelengths between 1 mm and 1 m. Unlike ionizing radiation such as X-rays, microwave exposure does not directly ionize DNA; however, it can induce both thermal and non-thermal biological effects [(9)].

• Thermal effects arise from the absorption of microwave energy by biological tissues, resulting in localized heating and subsequent elevation of cellular and organ temperature [(10)].

• Non-thermal effects occur in the absence of notable temperature increases and may involve modifications in cell membrane permeability, enzyme function, and ion transport mechanisms [(11)].

The biological response depends on several exposure parameters, including frequency, intensity, and modulation, polarization, and exposure duration [(12)].

Mobile Telephony

Mobile telephony is a two-way microwave communication between a handset and base station. The handsets radiate electromagnetic waves up to power levels of 1–2 W, the base stations up to 60 W; the direction of the base stations antenna emission is in beams, while the respective direction of the handsets antenna emission is nearly isotropic [(12)].

Microwave communication systems send and receive signals over distances from a few hundred kilometers to several tens of kilometers. The regulatory bodies of various countries set safety limits of radiofrequency exposure. But scientists are still validating the biological effects of long-term exposure [(13)].

Red Blood Cells (RBCs)

Erythrocytes (red blood cells) are the type of blood cells that constitutes the highest proportion among blood cells and serves as the main oxygen transporters. Their average size is about 8 µm in diameter, 2 µm in thickness (roughly a biconcave disc with a surface area of 163 µm2 and a volume of 90 femtoliters [;(13)]. Red blood cells are developed inside the bone marrow from stem cells. Upon maturation, they lose their nucleus, mitochondrial, and ribosomal contents, utilizing as much internal volume as possible for hemoglobin. An RBC lives approximately 100–120 days while traveling roughly 300 miles through the circulatory system [(14).]

Thanks to the biconcave structure and the high flexibility of their membranes, RBCs can deform and travel through capillaries smaller than their diameter without breaking [(15)].

Hemoglobin (Hb)

Hemoglobin is the major oxygen-carrying molecule in RBCs. It constitutes about 95% of the intracellular protein content, with an average concentration of 34 g/100 mL of packed cells [1]. Each red blood cell contains about 280 million hemoglobin molecules, enabling the transport of over one billion oxygen molecules [10]. In adult males, the total body hemoglobin mass reaches approximately 900 g, which is essential for oxygen delivery to tissues [15].

Structure of the Red Blood Cell Membrane

The erythrocyte membrane is a dynamic and flexible structure essential for the deformability and mechanical stability of RBCs [16]. It is composed of:

- 40% lipids
- 52% proteins
- 8% carbohydrates

The membrane consists of a phospholipid bilayer supported by a cytoskeletal network made of proteins such as spectrin, actin, ankyrin, band 3, and protein 4.1 [12]. The lipid bilayer provides elasticity and impermeability to most solutes, while cholesterol and phospholipids maintain proper membrane fluidity [17].

Two main types of membrane proteins exist:

1. Integral proteins, embedded within the lipid bilayer, forming transmembrane channels.
2. Peripheral proteins, loosely associated with the cytoplasmic surface, forming part of the cytoskeleton [18].

The spectrin–a ctin network provides the membrane with resistance to mechanical stress. Disruption of this network can lead to RBC fragmentation and hemolysis [19].

Sialic Acid

Red blood cell (RBC) membrane residues of sialic acid, on the top outer surface of the RBC membrane, contribute to the net negative surface charge of the membrane. This negative charge originating from the cell membrane creates a distinct area of negative repulsion, preventing unwanted cell aggregation in the bloodstream and facilitating healthy blood flow [20]

Additionally, a decrease of membrane sialic acid enhances rouleaux formation and increases blood viscosity, ultimately leading to decreased microcirculatory efficiency [21]. However, up to 67% of the surface sialic acid on red blood cells (RBC) is associated with glycophorin molecules [22]. Sialic acid is also important in cell membrane integrity and its life cycle [23].

RBC Aggregation

Aggregation of red blood cells is a reversible phenomenon that affects blood viscosity and flow behavior. RBCs aggregate at low shear stress to form rouleaux structures and once shear is increased, they disperse [24]. Over-aggregation can delay blood flow and oxygen delivery [25].

Erythrocyte Deformability

Deformability of erythrocytes which is also known as rheology or the ability of RBCs to change shape while remaining mimetic, allowing them to pass through narrow capillaries [26]

This is an important property for blood fluidity and in reaching adequate oxygenation in the tissue [27]. Factor determining the deformability includes the cytoskeleton structure, membrane viscosity and intracellular hemoglobin level [13]. Decreased deformability can disturb microcirculation and be responsible for many pathological conditions [6].

MATERIALS AND METHODS

Exposure Conditions

- Blood samples were exposed between two mobile phones (iphone13) at 1 cm distance, generating an electric field of for the iPhone 13 Pro, the reported SAR values are approximately 1.20 W/kg for head exposure and 1.19 W/kg for body exposure during cellular transmission. When multiple transmitters are active simultaneously (e.g., cellular + Wi-Fi), the combined SAR may reach around 1.35–1.58 W/kg [28]

Exposure durations were 1, 5, and 20 minutes

-After exposure to mobile phone, the exposed blood sample was taken and measurement of all parameters was done (computerized & manual); the same measurement was done before exposure as a controls, shown in Figure 1.

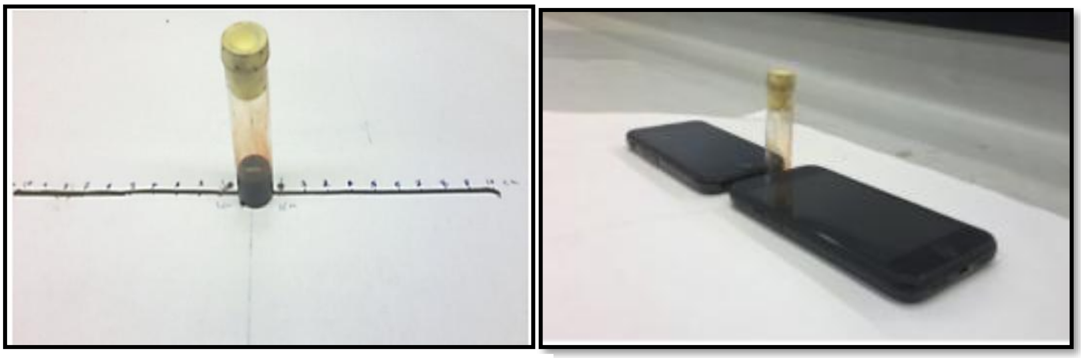

Figure 1: Blood sample & System of exposure

The experimental work was divided into two main parts after exposure:
A. Computerized Measurement

B. Manual Measurement

Part A – Computerized Measurement

Subject:
Blood samples were collected from 31 healthy volunteers (28 males, 3 females) aged 20–35 years without any chronic or current illness , shown in Figure 2.

Method:
Blood parameters including MCV, MCH, MCHC, Hb, Hct, and RBC count were analyzed using a Sysmex KX-21N (Japan) hematology analyzer.

Procedure:
- 5 ml of venous blood was collected from each volunteer and divided equally into two EDTA tubes:
  - Control sample: analyzed directly without microwave exposure.
  - Exposed sample: subjected to microwave radiation for 1, 5, and 20 minutes put tube between two mobile phones before analysis.

Figure 2: Sysmex device

Part B – Manual Measurement

Subjects:
Samples were obtained from 30 healthy individuals (20 males, 10 females) aged 24–45 years, with no disease history.

Tests Performed:

1. Packed Cell Volume (PCV) – determined using capillary micro Centrifugation. , shown in Figure 3

Figure 3: PCV measurement

2. Red Blood Cell Count (RBC) – measured using a Neubauer chamber and Hayem's solution.

3. Osmotic Fragility Test

a) Seventeen tubes (10 cm length, 1.5 cm diameter) were prepared with varying saline concentrations ranging from 0.9% to 0.1%.
b) Fifty µl of blood were added to each tube and incubated for 30–35 minutes, then centrifuged (Eppendorf) at 1200 rpm for 5 minutes at room temperature.

c) Hemolysis was measured using a double-beam UV/VIS spectrophotometer, the results are shown in Figure 4.

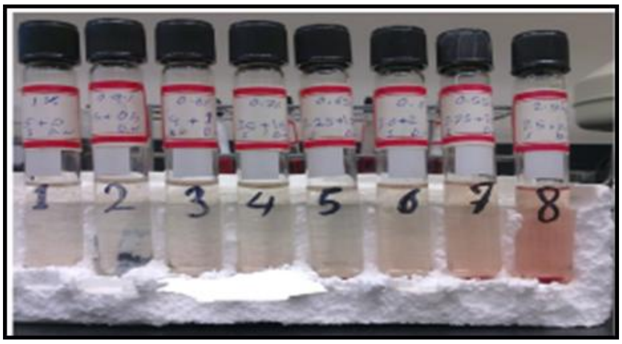

Figure 4: Osmotic fragility test

4 .Aggregation Test

We used a modified technique for studying erythrocyte aggregation kinetics during the different phase sedimentation.

This measurement used a fabricated chamber made by (5 microscopic glass slide), with dimensions (50 × 10 ×1 mm); erythrocyte suspension was filled up to 40 mm in height. The chamber was placed between laser source and the photocell (at constant distance) and the laser beam passed vertically exactly through the center of the sample column as shown in Figure 5.

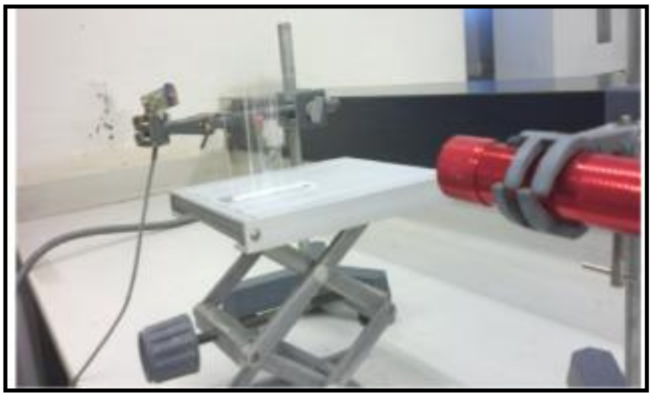

Figure 5: The chamber, laser &photodiode

5. Deformability Test

Determined by measuring the time required for blood to pass through a fine capillary tube (800–900 µm), shown in Figure 6.

Sample Preparation:

-10 ml venous blood mixed with 0.06 ml heparin.

-Portions used before and after microwave exposure to compare all parameters

-RBCs separated by centrifugation at 3000 rpm for 15 minutes.

- Physiological parameters (aggregation and deformability) were measured using prepared buffers (PBS, BSA, and Dextran).

Figure 6: System of deformability measurement

RESULTS AND DISCUSSION

Computerized experiments

In the automatic analysis of [31] blood samples by using Sysmex device (Kx-21N, A 7057, Japan), we try to assess the effect of microwave with different exposure times (1, 5 &20 minute) at a constant distance (1cm) between the mobile phone & the blood sample. The assessment includes measurement of hemoglobin (Hb) (g/dl), hematocrit (Hct) (%), mean corpuscular hemoglobin (MCH) (pg), mean corpuscular hemoglobin concentration (MCHC)(g/dl), and mean corpuscular volume (MCV)(fl).Table 1 shows a comparison of the effect of microwave radiation on blood parameters before exposure and after exposure to microwave in 1min time and1cm distance.

Table 1: The effect of microwave radiation on red blood cells before exposure (control) and after exposure for at 1cm distance &for 1 min exposure time

Parameters	**Before Exposure mean± SD (control)**	**After Exposure mean± SD**	**P value**
Hb (g/dl)	14.8±1.47	14.75±1.53	0.1651
Hct (%)	42.78±3.39	42.72±3.41	0.4196
MCH (pg)	28.56±2.64	28.63±2.68	0.4029
MCHC (g/dl)	34.45±1.16	34.6±1.33	0.0802
MCV (fl)	82.79±5.79	82.65±5.78	0.2808

n=31, Age (yr): 27.94±5.23

The results in the present study have shown Nonsignificant difference between the values of all blood parameters before &after exposure to microwave but it is clear that there is a decrease in hemoglobin value after exposure to microwave, (14.8±1.47 g/dl)(14.75±1.53 g/dl).While the mean corpuscular hemoglobin, the mean corpuscular hemoglobin concentration showed an increase values after exposure to microwave of the cellular phone (28.56±2.64 pg) (28.63±2.68pg), (34.45±1.16 g/dl) (34.6±1.33 g/dl) respectively, on the after hand, there was a decrease in mean corpuscular volume value after exposure to microwave (82.79±5.79 fl) (82.65±5.78 fl). Table 2 represents the data collected before &after exposure to microwave 5min time&1cm distance.

Table 2: The effect of microwave radiation on red blood cells before exposure (control)and after exposure at 1cm distance & for 5 min exposure time

Parameters	Before Exposure mean± SD (control)	After Exposure mean± SD	P value
Hb (g/dl)	11.18±1.4	11.02±1.43	0.5381
Hct (%)	40.72±4.0	39.54±3.82	0.2897
MCH (pg)	21.52±1.68	21.82±1.69	0.052
MCHC (g/dl)	27.42±1.05	27.8±1.07	0.0833
MCV (fl)	78.42±3.53	78.38±3.31	0.8303

n=31, Age (yr): 29.4±6.58

The effect of exposure microwave to a longer time (5min) also shows Nonsignificant reduction of hemoglobin like the effects of exposure to (1min).The hemoglobin concentration (11.18±1.4 g/dl) (11.02±1.43g/dl), as well as insignificant increase in mean corpuscular hemoglobin value, (21.52±1.68 pg) (21.82±1.69 pg), mean corpuscular hemoglobin concentration also insignificant increased value, (27.42±1.05 g/dl) (27.8±1.07 g/dl), insignificant decrease in mean corpuscular volume value, (78.42±3.53 fl) (78.38±3.31 fl). Table 3 represents the data collected before exposure to microwave &after exposure to microwave in 20min time&1cm distance.

Table 3: the effect of microwave radiation on red blood cells before (control) and after exposure at 1cm distance & for 20 min exposure time

Parameters	Before Exposure mean± SD (control)	After Exposure mean± SD	P value
Hb (g/dl)	12.2±1.27	12.04±1.28	**0.0349**
Hct (%)	42.28±4.55	41.24±5.62	0.4299
MCH (pg)	25.0±1.12	29.22±7.75	0.3138
MCHC (g/dl)	28.86±0.88	29.38±2.71	0.5828
MCV (fl)	86.56±3.0	86.58±2.89	0.9156

n=31, Age (yr): 29.8±5.76

When the duration of exposure was extended to 20 minute we found that the reduction in hemoglobin becomes significant, while still there is an increase (MCH), (MCHC) value with normal (MCV). As the shown in Table (1), Table (2) & Table (3) we found that there is reduction in hemoglobin value on exposure to microwave but this reduction was only significant in (20 min) exposure. Hemoglobin concentration before exposure to (20 min) at control was (12.2± 1.27 g/dl) &after exposure (12.04±1.28 g/dl) p-value (0.0349).

Manual experiments

This experiment include measurement RBC count*10^3(cell/mm^3), Flow rate (sec), Aggregation measurement, osmotic fragility. In this experiment on the 21 blood samples; their age was (yr) (33.3±6.9)

&PCV% (43.2±4.6) exposed to microwave for 1min at1cm distance. It is clear that that there is a significant increase in flow rate value on exposure to microwave (58.68±21.61sec) (70.66±33.88 sec), the p-value (0.0087). Table 4 shows red blood cell count *10^4 (cell/mm^3) before exposure &after exposure to micro wave; there was a significant reduction in the number of RBC count*10^4(cell/mm^3) after exposure to microwave, (501.61±46.89 (cell/mm^3)) (481.26±48.74 (cell/mm^3)), the p-value (0.003).

aggregation time (min) there is insignificant decreased in AT value after exposure to microwave (6.06 ±2.0 min) (5.51 ± 1.52min), also insignificant decreased in 1DAT value (5.08± 1.66 min) (4.80± 1.17 min), insignificant decreased in 3DAT value (7.24±2. 81 min) (6.48±1.82 min), but show significant in ST after exposure to microwave (18.43±5.78) (16.69±3.97) the ρ-value (0.0256).Figure 5 show the aggregation time value after exposure for min aggregation rate there is Nonsignificant in RA value after exposure (0.74±0.21) (0.74± 0.27), &insignificant increased in R1DS value after exposure value (3.08± 1.35) (3.48± 0.84),&Nonsignificant increase in R3DS value after exposure (4.42±1.46) (4.73±1.71), but show significant in Slope after exposure to microwave (2.81±0.76) (3.00±0.75) the ρ-value (0.0313). In this exposure we see flow rate increased that mean significant decreased in flow rate ρ-value (0.008663),and red blood cell count is reduce significantly ρ-value (0.002972),&the aggregation although not significant increased but ST (min) decreased or significantly ρ-value (0.0256)&significant increase in Slope ρ-value (0.0313) show that in Table 4.

Table 4: The effect of microwave radiation on red blood cells before exposure (control)&after exposure for (1cm distance &1 min exposure time).

Parameters		**Before Exposure mean± SD (control)**	**After Exposure mean± SD**	**P value**
Flow time (sec)		58.68±21.61	70.65±33.87	0.0086
RBC count * 10^3 (cell/mm^3)		501.6±46.89	481.26±48.74	0.0029
Aggregation	**AT (min)**	6.06±2.0	5.51±1.52	0.1175
Time	**1DAT (min)**	5.08±1.66	4.80±1.17	0.3560
	3DAT (min)	7.24±2.81	6.48±1.82	0.1277
	ST (min)	18.43±5.78	16.69±3.97	0.0256
Rate	**RA**	0.74±0.21	0.74±0.27	0.9694
	R1DS	3.08±1.35	3.48±0.84	0.1648
	R3DS	4.42±1.46	4.73±1.71	0.2764
	Slope	2.81±0.76	3.00±0.75	0.0313

n=31, Age (yr): 33.3±6.9

DISCUSSION

Microwaves are electromagnetic waves with frequencies above 1 GHz and wavelengths between those of infrared and short waves. Microwave radiation is a type of non-ionizing electromagnetic radiation found in the environment and may pose potential health risks through both thermal and non-thermal effects [29, 30].

The thermal effect arises when microwave energy is absorbed by water molecules within biological tissues, leading to the generation of heat. This phenomenon is commonly associated with higher frequencies, such as 2.45 GHz. In the current study, no thermal frequencies were employed; rather, the investigation focused on non-thermal effects produced within the 900–1800 MHz frequency range [31].

Non-thermal effects of microwaves are mainly associated with dielectric interactions between the electromagnetic field and water molecules or cell membranes. Although the photon energy at 900 MHz

(~4×10^{-6} eV) or 1800 MHz (~7×10^{-6} eV) is far below the ~1 eV needed to break chemical bonds, biological alterations may still occur depending on exposure parameters such as frequency, power density, polarization, modulation, and exposure duration (31, 32).

In this study, automatic blood analysis revealed a significant reduction in hemoglobin (Hb) concentration after 20 minutes of microwave exposure, whereas 1 and 5 minutes of exposure showed no significant effect. The observed decrease in Hb may be attributed to a reduction in red blood cell (RBC) count detected through manual analysis, indicating that microwave radiation may influence RBC membrane integrity or induce cell shrinkage. Furthermore, the possibility of red blood cell hemolysis was taken into consideration, as hemolytic breakdown could contribute to the decline in Hb levels; however, all samples were handled under controlled conditions to minimize hemolysis and ensure that the measured changes reflected the true effect of microwave exposure (33).

An increase in mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC) was observed, likely due to reduced RBC size rather than an actual increase in Hb synthesis. These findings differ from those of Sedehi M. Esfahani (2007)(34), who reported increased Hb values after in vivo exposure at 2.45 GHz _ a much higher (thermal) frequency _ and are partially consistent with Adang (2009), who found increased RBC counts following low-level microwave exposure possibly due to erythropoietin stimulation (35).

Manual results in our study showed a highly significant reduction in RBC count even after only 1 minute of exposure, possibly caused by membrane protein denaturation or changes in the electrostatic charge of the cell surface. A similar decrease in blood cell counts under microwave exposure was reported by Howard W. Fisher (2008)(36).

The observed increase in flow time and reduction in aggregation time likely result from alterations in the surface charge and elasticity of RBC membranes, possibly due to changes in sialic acid content (37). Osmotic fragility tests revealed a slight, non-significant increase in hemolysis after exposure, indicating mild impairment of membrane stability, consistent with recent evidence showing RBC membrane permeability changes after exposure to low-power microwave radiation (27,38).

Overall, while the exact mechanisms of non-thermal microwave interactions with biological systems remain uncertain, recent studies confirm that such effects are parameter-dependent, emphasizing the need for standardized experimental models to assess bio electromagnetic safety (39,).

CONCLUSION

The present study demonstrates that exposure to electromagnetic radiation generated by mobile phones can influence red blood cell (RBC) parameters, particularly after prolonged exposure. A significant reduction in hemoglobin (Hb) concentration and RBC count was observed following 20-minute exposure, suggesting possible alterations in cell membrane integrity or deformability. Additionally, changes in flow rate and aggregation time indicate potential modification of membrane surface charge and elasticity. These results support the hypothesis that non-thermal microwave radiation can induce subtle but measurable effects on erythrocyte morphology and function. Further in-depth molecular and in vivo studies are recommended to clarify the underlying mechanisms and evaluate the potential health implications of chronic electromagnetic exposure.

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CONFLICT OF INTEREST

The author declares no conflict of inte**rest** regarding the publication of this research paper.

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ETHICAL STATEMENT

All experimental procedures were conducted in accordance with the ethical standards of the College of Pharmacy, Al-Nahrain University, and the principles outlined in the Declaration of Helsinki (2013). Informed consent was obtained from all volunteers prior to blood sample collection, and all personal data were handled with full confidentiality

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تأثير الإشعاع الكهرومغناطيسي الناتج عن الهواتف المحمولة على خلايا الدم الحمراء

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الملخص

الهدف :تتوسع التقنيات اللاسلكية بسرعة كبيرة، مما أدى إلى زيادة ملحوظة في تعرض الإنسان للإشعاع الكهرومغناطيسي(EMR) ، وخاصة في نطاق الترددات الميكروية المنبعثة من الهواتف المحمولة. هدفت هذه الدراسة إلى فحص تأثير الإشعاع الميكروي الناتج عن الهواتف المحمولة على خلايا الدم الحمراء البشرية (RBCs) في المختبر.

الطرق :جُمعت عينات دم من متطوعين أصحاء وتعرّضت لأشعة الميكروويف المنبعثة من الهواتف المحمولة على مسافة 1 سم لمدة 1، 5، و20 دقيقة. تم تحليل المعايير الدموية الحاسوبية واليدوية، بما في ذلك تركيز الهيموغلوبين(Hb) ، حجم الخلايا المكدسة(Hct) ، عدد خلايا الدم الحمراء، متوسط محتوى الهيموغلوبين في الخلية(MCH) ، متوسط تركيز الهيموغلوبين في الخلية(MCHC) ، بالإضافة إلى التراص، قابلية التشوه، والهشاشة الأسموزية.

النتائج :لوحظ انخفاض معنوي في تركيز الهيموغلوبين بعد 20 دقيقة من التعرض، بالإضافة إلى انخفاض معنوي في عدد خلايا الدم الحمراء بعد دقيقة واحدة فقط من التعرض. كما ازداد معدل التدفق بشكل ملحوظ، وأظهرت مؤشرات التراص وقابلية التشوه تغيرات تدل على تأثر غشاء خلايا الدم الحمراء.

الاستنتاج :تشير النتائج إلى أن التعرض للإشعاع الميكروي غير الحراري يمكن أن يؤثر في شكل ووظيفة خلايا الدم الحمراء، ويرجح أن ذلك ناتج عن تغيّرات في سلامة الغشاء وشحنته السطحية، مما قد تكون له آثار على لزوجة الدم عند التعرض الطويل للإشعاع الكهرومغناطيسي.

الكلمات المفتاحية :الإشعاع الكهرومغناطيسي، الموجات الميكروية، خلايا الدم الحمراء، الهيموغلوبين، التأثيرات غير الحرارية.