



# Effect of Acute and Long-Term Extremely Low-Frequency Electromagnetic Fields Exposure on Murine Haematological Parameters

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**Abstract:** The present study evaluated the effects of exposure to diverse extremely low-frequency electromagnetic fields (ELF-EMFs) conditions on mice haematological parameters. Three independent experiments were performed as follows: (1) animals acutely exposed to magnetic flux densities of 1.0, 1.5, and 2.0 mT for 72 h in a calibrated solenoid, (2) a combined treatment of 2.0 mT ELF-EMFs with simultaneous exposure to 5 mg/kg of the cytotoxic agent mitomycin-C (MMC) for 72 h, and (3) a prolonged 8 h daily exposure to 2.0 mT ELF-EMFs for 10 days. All acute exposures included a negative control not exposed to magnetic fields and a positive control treated only with MMC. In the experiment with prolonged exposure, only a negative control was included. We used 12-week-old male BALB/c mouse strains grown in our Facultad de Ciencias Biológicas-UANL, México facility. Blood was obtained from the periorbital cavity, and haematological parameters were evaluated before and after the magnetic field exposure. Haematological tests included total plasma proteins, haemoglobin, and differential leukocyte count. Results showed that ELF-EMF acute exposure significantly ( $p < 0.05$ ) increased the percentage of neutrophils as a part of the white blood cell count and decreased that of lymphocytes. The combined exposure to ELF-EMFs and MMC only showed an increase in haemoglobin. Furthermore, EMF-prolonged exposure did not affect haematological parameters.

**Keywords:** Extremely low-frequency electromagnetic fields (ELF-EMFs), haematological parameters, mice, BALB/c mouse strain.

## Introduction

Blood effectively indicates a mammal's physiological state, and many measurable parameters have been established in haematology. It has been frequently used as a physiological indicator to evaluate the influence of various physical and chemical stressors from environmental pollution or occupa-

tional exposure (ALIMOHAMMADI & DANESH 2014). Some studies have reported that exposure to extremely low-frequency electromagnetic fields (ELF-EMFs) may affect haematological parameters, causing changes in the count and morphology of blood cells, alterations in coagulation, platelet aggregation, and blood viscosity, and modifications in the levels of haemoglobin, haematocrit, iron, and other

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plasma components. These changes reflect a state of oxidative stress, inflammation, or cell damage induced by ELF-EMFs and may have consequences for cardiovascular, immunological, and oncological health (AHLBOM et al. 2001, ZAMANIAN & HARDIMAN 2005, KIVRAK et al. 2017).

It is known that blood cells are sensitive to non-ionizing radiation at the range tested in our study, and one of the main observed effects is to alter cell proliferation (CETIN et al. 2006, JELODAR et al. 2011, ABDOLMALEKI et al. 2012). In particular, it has been reported that lymphocytes are susceptible to many types of radiation. Since the middle of the last century, TROWELL (1952) indicated the high sensitivity of lymphocytes to ionising radiation. Recently, several studies (HEYLMANN et al. 2014, PAGANETTI 2023) have reported the radiosensitivity of lymphocytes. Moreover, we have used lymphocytes as a well-cell model to evaluate the cytotoxic or genotoxic effects of ELF-EMFs (HEREDIA-ROJAS et al. 2017, 2018).

In this regard, some studies have reported that ELF-EMF exposure decreases mammal lymphocyte count (BOSCOLO et al. 2001, BONHOMME-FAIVRE et al. 2003). In contrast, increases in white blood cells, including lymphocytes, have also been reported (MARINO et al. 1977, DIDENKO et al. 1986, COS-SARIZZA et al. 1989). Moreover, many other research groups have shown no significant changes produced by electromagnetic fields in these cells (ZWINGELBERG et al. 1993, MARGONATO et al. 1995, UBEDA et al. 1997).

More recently, ALGHAMDI & EL-GHAZALY (2012) studied the effects of EMFs emitted by mobile phones on some haematological parameters of the male BALB/c mouse strain. They showed that EMF exposure decreased haemoglobin, haematocrit, red blood cell, and platelet counts and increased total white blood cell and lymphocyte counts. Similarly, SANI et al. (2018) evaluated the effects of mobile phone electromagnetic non-ionizing radiation (EMR) on some haematological parameters in male albino rats. Their results showed that EMR exposure increased red blood cells, haemoglobin, and mean corpuscular haemoglobin, whereas white blood cells remained unaltered. USMAN et al. (2012) exposed Swiss albino mice to Global System for Mobile Communication (GSM) window frequencies (900 MHz and 1800 MHz) and compared their haematological parameters with those of sham-exposed mice. The complete blood count showed that the haematological parameters of both sham-exposed and EMF-exposed mice were within the normal range. However, the mean values of haematological parameters were significantly affected by prolonged

exposure. LAI et al. (2016) investigated the effects of 100  $\mu$ T/50-Hz ELF-EMFs on haematograms and blood chemistry in rats. They exposed rats to ELF-EMF for 20 hours daily for three months, compared with the sham-exposed group, and found no significant differences between the two groups. In addition, JBIREAL et al. (2018) reviewed the effects of ELF-EMFs on haematological parameters in experimental models of humans and other species. They collected and analysed previous studies from 1997 to 2018 that used different sources, frequencies, intensities, and durations of EMF exposure. They showed that EMF exposure caused harmful effects on blood cells, such as several disturbances of haematological parameters. They suggested that EMF exposure may cause adverse effects on living organisms by affecting the hematopoietic system.

On the other hand, HOSSEINABADI et al. (2019) studied the effect of long-term occupational exposure to ELF-EMFs on haematological parameters among many employees of a power plant in Iran, compared to unexposed employees. They measured conventional haematological parameters, such as white blood cell (WBC) and red blood cell (RBC) counts, lymphocyte percentage, mean corpuscular volume, platelet count, and procalcitonin. Their results showed that the exposed group had significantly higher levels of these parameters than the unexposed group. In addition, MOSLEMI et al. (2023) evaluated the effects of ELF-EMF exposure on blood parameters and liver enzymes of personnel working in high-voltage power stations in a petrochemical industry in Iran. They compared two groups of workers, one exposed to ELF-EMFs and one unexposed, and found no significant differences between them.

Because of the conflicting results reported in the literature on the effect of ELF-EMFs on the health of living organisms, blood tissue was selected as a suitable physiological indicator to assess this effect, as it reflects the status of various body systems. Therefore, the present study aimed to evaluate the impact of acute and chronic exposure to 60 Hz ELF-EMFs on the haematological parameters of mice.

## Materials and Methods

### Animals

A sexually mature, 12-week-old male BALB/c mouse strain (weighing 25g to 30g) was used in this study, raised in our breeding colony. Mice were kept in a pathogen- and stress-free environment at 24 °C, under a light-dark cycle (light phase, 06:00 h to 18:00 h), and given water and food *ad libitum*. Af-

ter a 10-day quarantine period, they were randomly distributed into experimental and control groups. All animal procedures were developed following University Animal Care and Use for Research Protocols, which are based on the National Guidelines for Ethics and Biosafety under the General Law of Health for issues regarding Health Research (Ministry of Health, Mexico).

### ELF-EMF Exposure Facility

As previously reported, we used a standardised and characterised in-house shielded magnetic field exposure facility (HEREDIA-ROJAS et al. 2017, HEREDIA-ROJAS et al. 2018). In brief, a coil was prepared by winding 552 turns of enamel-insulated copper wire (1.3 mm diameter), which produced a 13.5 cm radius and 71 cm length cylindrical solenoid. It was connected to step-down and variable transformers and supplied from a 110 V AC source. Animals were allocated in the middle of this structure in a homogeneous magnetic field area and kept at  $25 \pm 0.2$  °C and 45% humidity. Sham-exposed animals were used as negative controls, which were placed in the same setup but with the magnetic field device turned off. Magnetic flux density was determined using a Hall-effect probe (Bell FW 6010 Teslameter, Orlando, FL, USA). In addition, an attached oscilloscope (BK-Precision model 2120, Dynascan Corp., Chicago, IL) was used to monitor the resulting field. A 60-Hz alternating sinusoidal magnetic field was then generated. Frequency content was almost pure 60 Hz (< 2% total harmonic distortion), and 0.3  $\mu$ T and 20  $\mu$ T values were observed for respective background magnetic and local geomagnetic fields, respectively. To maintain the exposure geometry, a plastic separator was inserted in the solenoid to allow placing mice in pre-determined zones, where the magnetic flux density was 1.0, 1.5, and 2.0 mT oscillating magnetic field (rms value).

### Experimental Design

The following independent experiments were conducted: (1) Animals acutely exposed to magnetic flux density of 1.0 mT for 72 h, (2) Acute exposure to 1.5 mT/72h, (3) Acute exposure to 2.0 mT/72 h, (4) Co-exposure of 2.0 mT and 5 mg/kg of the cytotoxic agent mitomycin-C (MMC) for 72 h, and (5) prolonged 8-h daily exposure for 10 days to 2.0 mT ELF-EMFs. Each acute treatment regimen included a negative control (sham-exposed animals) and a positive control of animals intraperitoneally injected with MMC at the beginning of the experiments. The long-term or prolonged exposure included only sham-exposed and ELF-EMF-exposed groups. Three

mice were used for each treatment regimen and control, as well as three haematological tests per animal, for a total of nine haematological determinations for each studied group.

### Haematological Analysis

Conventional haematological tests (BAIN et al. 2006) were performed, which included total plasma protein (TPP), haemoglobin (HB) and differential leukocyte count, neutrophils (NEU), eosinophils (EOS), basophils (BAS), lymphocytes (LYM), and monocytes (MON). Haematological parameters were evaluated for each animal before treatments (0 h) and at the end of treatments (72 h for acute treatment and 10 days for prolonged exposure). Blood samples were obtained from the periorbital cavity using glass heparinised tubes. TPP was evaluated by a refractometer (A300 CL Clinical, Japan) and was expressed as g/dl. HB was assessed with a Haemoglobin meter (HemoCue Model Hb201+ Beracah-Medica, Mexico) and was expressed as g/dl. Leukocyte counts were reported as percentages after microscopic analysis of air-dried smears that were stained with 5% May-Grünwald-Giemsa for 12 min to 15 min and evaluated using a Leica DM 2500 microscope (Leica Microsystems, Milton Keynes, UK) at 1000x. To determine cell percentages, 100 random and consecutive white cells were scored.

### Statistical Analysis

Data were analysed by the Kolmogorov-Smirnov test to estimate the normal distribution and the Levene test for homogeneity of variances ( $p < 0.05$ ). They were subjected to the paired Student's *t*-test if they were normally distributed. If the distribution was non-normal, data were analysed with the non-parametric Wilcoxon *t*-test. We used the IBM-SPSS statistical package version 22.0 (SPSS Inc., Chicago, IL, USA).

## Results

Table 1 shows the means  $\pm$  standard deviations of analysed haematological parameters of mice acutely exposed to 1.0 mT ELF-EMFs for 72 h. Results showed an increased TPP value in the magnetic field exposure and the positive control treated with MMC ( $p < 0.01$ ) when compared to the values before (at the beginning of the experiment = 0 h) versus after treatment (at the end of the experiment = 72 h). In this bioassay, the NEU number was significantly ( $p < 0.01$ ) increased in the magnetic field exposure and the positive control groups. In contrast, a significant ( $p < 0.01$ ) decrease in the LYM number was found in magnetic fields-exposed animals and the positive

MMC control group. No statistically significant differences were observed for negative sham-exposed controls ( $p > 0.05$ ). Table 2 shows results of haematological parameters from animals continuously exposed to 1.5 mT ELF-EMF for 72 h. Results are also expressed as means  $\pm$  standard deviations and indicated the same significant ( $p < 0.01$ ) results as mentioned above for 1.0 mT acute exposure (Table 1), including increased TPP and NEU values and decreased LYM value in mice exposed to magnetic fields.

Table 3 shows the results of haematological parameters from mice acutely exposed to ELF-EMFs at 2.0 mT/72 h of continuous exposure. Results, expressed as means  $\pm$  standard deviations, indicated a significant ( $p < 0.05$ ) decrease of TPP and HB parameters at the end of the experiment (after 72 h of exposure) when compared to the initial values. Regarding leucocyte counts, significant ( $p < 0.05$ ) increased NEU number and decreased LYM value were observed in mice after 72 h of magnetic field exposure. Positive MMC controls showed the same trend as the ELF-EMF exposed groups. No statistically significant ( $p > 0.05$ ) differences were observed for sham-exposed negative controls.

In addition, Table 4 shows the means  $\pm$  standard deviations of animals simultaneously treated with 2.0 mT ELF-EMF continuous exposure/72 h plus 5 mg/kg MMC. They indicated a slight and significant ( $p < 0.01$ ) augmentation in the HB parameter in co-exposed animals. However, positive MMC control showed a decreased HB value. Regarding white cell counts, no statistically significant ( $p > 0.05$ ) differences were found between 0 h and 72 h of co-exposure condition. Positive MMC controls showed significant ( $p < 0.01$ ) differences, except for EOS and BAS parameters ( $p > 0.05$ ).

Furthermore, Table 5 shows the results from prolonged mice exposure (10 d/8 h daily to 2.0 mT ELF-EMFs). Results are also expressed in terms of means  $\pm$  standard deviations. No significant ( $p > 0.05$ ) changes were observed when comparing haematological parameters at the beginning of the experiment (0 h) with those at the end of the bioassay (10 days). No positive MMC control was included in this bioassay because chronic exposure to MMC resulted in the death of mice.

## Discussion

The haematological effects of magnetic fields have been widely discussed in recent years. The question has been raised about whether exposure to such fields causes alterations in blood parameters. The

design of the present study involved the evaluation of the effect of ELF-EMFs on conventional haematological parameters in mice exposed to different (1.0, 1.5, and 2.0 mT) magnetic flux conditions and a combined treatment simultaneously using ELF-EMFs and MMC. Furthermore, a prolonged (10 days daily) exposure to magnetic fields was conducted. The major findings were that ELF-EMF acute exposure decreased LYM number and increased TPP and NEU values. Regarding LYM counts, our results agreed with BOSCOLO et al. (2001) and BONHOMME-FAIVRE et al. (2003), who reported a reduction in lymphocyte numbers after ELF-EMF exposure in mice and humans. In contrast, ALGHAMDI & EL-GHAZALY (2012) found an increase in white blood cells and lymphocyte count after exposure of mice to EMF emitted by mobile phones. In a previous study, we showed that ELF-EMFs with similar characteristics and at the same flux densities used in the current study led to stimulation of lymphocyte proliferation *in vitro* (HEREDIA-ROJAS et al. 2001). In a recent survey, HOSSEINABADI et al. (2019) also observed high levels of lymphocytes in humans occupationally exposed to ELF-EMFs. On the other hand, several investigations reported no changes induced by electromagnetic radiation on complete blood cell counts, including lymphocytes, in rodents exposed to mobile phone frequencies (USMAN et al. 2012, SANI et al. 2018). Furthermore, LAI et al. (2016) found no significant differences between rats exposed to 50 Hz ELF-EMFs and sham-exposed in haematograms. Moreover, WANG et al. (2021) demonstrated that exposure to ELF-EMF at the intensity of 1 mT for 24 weeks did not affect haematologic indexes in adult rats. More recently, MOSLEMI et al. (2023) also found no effects of ELF-EMFs on humans occupationally exposed to conventional haematological parameters.

Concerning TTP increased values, our results agree with AMARA et al. (2006), who found a 62% increase in plasmatic total protein levels in rats. However, they exposed the animals to static magnetic fields. Our study also showed NEU increased values in mice acutely exposed to magnetic fields, which does not agree with a previous study conducted by LIPPI et al. (2016), who reported that 30-min exposure to radiofrequency waves from mobile phones induced a significant decrease in many neutrophil parameters in humans.

In the present study, we found a slight augmentation in the HB parameter when animals were simultaneously treated with 2.0 mT ELF-EMFs continuous exposure/72 h plus mg/kg MMC. In this regard, ALGHAMDI & EL-GHAZALY (2012) suggested that ELF-

**Table 1.** Effect of 60 Hz ELF-EMFs on haematological parameters of male BALB/c mouse strain acutely (72 h) exposed to 1.0 mT magnetic flux density and controls, negative (-) (sham-exposed animals), and positive (+) (MMC-5 mg/kg). *p* values are indicated as \* *p*<0.05 and \*\**p*<0.01. (a) In the cases of non-normal data distribution, the non-parametric Wilcoxon *t*-test was applied. TPP and HB were measured in g/dL, and cell counts were expressed as percentages.

Studied parameters	Mean ± SD			<i>p</i>		
	Sham control (-)	MMC control (+)	1.0 mT ELF-EMF	Sham control (-)	MMC control (+)	1.0 mT ELF-EMF
TPP 0 h	5.53±0.489	3.800±1.540	6.280±1.230	0.09	0.042*	0.003**
TPP 72 h	6.02±0.650	5.440±1.600	7.950±0.781			
HB 0 h	17.33±1.561	17.66±0.567	17.16±0.500	0.051	0.001**	0.174
HB 72 h	15.83±1.456	13.88±1.219	16.83±0.485			
NEU 0 h	36.44±4.186	48.00±7.952	45.750±9.701	0.461	0.004**	0.003**
NEU 72 h	35.22±2.438	61.66±9.394	61.550±9.013			
EOS 0 h	0.330±0.050	0.110±0.033	0.000±0.000	0.090 <sup>a</sup>	0.594 <sup>a</sup>	0.081 <sup>a</sup>
EOS 72 h	0.290±0.044	0.220±0.044	0.330±0.050			
BAS 0 h	0.000±0.000	0.110±0.333	0.000±0.000	0.347 <sup>a</sup>	1 <sup>a</sup>	0.347 <sup>a</sup>
BAS 72 h	0.110±0.333	0.00±0.000	0.110±0.333			
LYM 0 h	61.00±4.000	60.00±11.297	77.44±8.308	0.16	0.002**	0.001**
LYM 72 h	63.33±2.549	42.11±8.462	24.11±4.400			
MON 0 h	2.110±1.536	1.440±0.726	0.850±0.440	0.088	0.367	0.596
MON 72 h	1.110±0.600	1.000±1.224	1.000±0.707			

**Table 2.** Effect of 60 Hz ELF-EMFs on haematological parameters of male BALB/c mouse strain acutely (72 h) exposed to 1.5 mT magnetic flux density and controls, negative (-) (sham-exposed animals), and positive (+) (MMC-5 mg/kg). *p* values are indicated as \* *p*<0.05 and \*\**p*<0.01. (a) In the cases of non-normal data distribution, the non-parametric Wilcoxon *t*-test was applied. TPP and HB were measured in g/dL, and cell counts were expressed as percentages.

Studied parameters	Mean ± SD			<i>p</i>		
	Sham control (-)	MMC control (+)	1.5 mT ELF-EMF	Sham control (-)	MMC control (+)	1.5 mT ELF-EMF
TPP 0 h	5.530±0.980	4.100±0.477	5.651±0.240	0.333	0.002**	0.002**
TPP 72 h	6.020±1.100	5.440±0.950	6.067±0.223			
HB 0 h	17.33±1.661	17.66±0.567	15.39±1.416	0.066	0.001**	0.414
HB 72 h	15.83±1.559	13.88±1.219	14.80±1.563			
NEU 0 h	36.44±4.186	47.852±7.592	45.70±8.366	0.461	0.003**	0.008**
NEU 72 h	35.22±2.438	61.65±9.394	67.56±9.988			
EOS 0 h	0.330±0.500	0.325±0.333	0.660±0.707	0.594 <sup>a</sup>	0.748 <sup>a</sup>	0.132 <sup>a</sup>
EOS 72 h	0.220±0.440	0.385±0.440	0.220±0.440			
BAS 0 h	0.000±0.000	0.110±0.333	0.000±0.000	0.065 <sup>a</sup>	1 <sup>a</sup>	0.153 <sup>a</sup>
BAS 72 h	0.220±0.333	0.000±0.000	0.220±0.440			
LYM 0 h	61.520±4.356	60.00±7.297	60.20±6.418	0.565	0.004**	0.003**
LYM 72 h	60.520±2.654	48.25±7.462	49.52±6.520			
MON 0 h	2.110±1.536	1.440±0.726	2.000±1.224	0.088	0.33	0.544
MON 72 h	1.110±0.600	1.000±1.224	1.660±1.100			

**Table 3.** Effect of 60 Hz ELF-EMFs on haematological parameters of male BALB/c mouse strain acutely (72 h) exposed to 2.0 mT magnetic flux density and controls, negative (-) (sham-exposed animals), and positive (+) (MMC-5 mg/kg). *p* values are indicated as \* *p*<0.05 and \*\**p*<0.01. (a) In the cases of non-normal data distribution, the non-parametric Wilcoxon *t*-test was applied. TPP and HB were measured in g/dL, and cell counts were expressed as percentages.

Studied parameters	Mean ± SD			<i>p</i>		
	Sham control (-)	MMC control (+)	2.0 mT ELF-EMF	Sham control (-)	MMC control (+)	2.0 mT ELF-EMF
TPP 0 h	6.650±0.714	6.700±1.367	7.383±0.109	0.862	0.023*	0.012*
TPP 72 h	6.700±0.456	5.050±1.414	7.050±0.334			
HB 0 h	17.92±.902	17.92±0.984	19.58±1.353	0.288	0.021*	0.003**
HB 72 h	17.42±1.023	16.120±1.858	15.17±1.598			
NEU 0 h	13.00±5.545	28.440±6.187	39.11±9.285	0.073	0.020*	0.002**
NEU 72 h	19.89±9.253	36.56±7.11	54.22±8.526			
EOS 0 h	0.333±0.707	0.222±0.441	0.111±0.333	0.347 <sup>a</sup>	0.347 <sup>a</sup>	1.0 <sup>a</sup>
EOS 72 h	0.111±0.333	0.111±0.333	0.111±0.333			
BAS 0 h	0.000±0.000	0.000±0.000	0.000±0.000	0.347 <sup>a</sup>	1.0 <sup>a</sup>	1.0 <sup>a</sup>
BAS 72 h	0.111±0.333	0.000±0.000	0.000±0.000			
LYM 0 h	85.56±5.102	80.33±14.550	77.33±8.157	0.096	0.009**	0.08*
LYM 72 h	79.56±8.791	62.89±10.11	62.89±8.526			
MON 0 h	1.111±0.781	1.000±0.707	1.000±0.500	0.26 <sup>a</sup>	0.77 <sup>a</sup>	0.517 <sup>a</sup>
MON 72 h	0.744±0.527	0.444±0.527	0.844±0.500			

**Table 4.** Effect of 60 Hz ELF-EMFs on haematological parameters of male BALB/c mouse strain simultaneously treated with an acute (72 h) exposure to 2.0 mT magnetic flux density plus MMC-5 mg/Kg. Negative controls (sham-exposed animals) (-), and positive controls (+) (animals treated only with MMC-5 mg/Kg) were included. *p* values are indicated as \* *p*<0.05 and \*\**p*<0.01. (a) In the cases of non-normal data distribution, the non-parametric Wilcoxon *t*-test was applied. TPP and HB were measured in g/dL, and cell counts were expressed as percentages.

Studied parameters	Mean±SD			<i>p</i>		
	Sham control (-)	MMC control (+)	2.0 mT+MMC	Sham control (-)	MMC control (+)	2.0 mT+MMC
TPP 0 h	6.889±0.372	6.378±0.205	6.567±0.324	0.544	0.001**	0.288
TPP 72 h	6.800±0.218	5.678±0.424	6.400±0.320			
HB 0 h	16.78±1.481	16.33±0.968	15.50±0.750	0.106	0.002**	0.001**
HB 72 h	15.72±1.121	14.44±1.210	16.80±0.590			
NEU 0 h	28.11±5.261	33.33±9.950	20.44±5.593	0.259	0.004**	0.496
NEU 72 h	25.121±5.571	47.67±8.276	22.67±7.798			
EOS 0 h	0.222±0.441	0.333±0.500	0.222±0.441	0.594 <sup>a</sup>	0.063 <sup>a</sup>	0.150 <sup>a</sup>
EOS 72 h	0.111±0.333	0.000±0.000	0.000±0.000			
BAS 0 h	0.000±0.000	0.000±0.000	0.000±0.000	0.347 <sup>a</sup>	1 <sup>a</sup>	1 <sup>a</sup>
BAS 72 h	0.111±0.333	0.000±0.000	0.000±0.000			
LYM 0 h	70.33±10.14	74.78±5.118	77.78±5.911	0.14	0.001**	0.594
LYM 72 h	77.89±10.73	41.56±8.172	76.22±9.497			
MON 0 h	1.222±0.666	1.556±0.527	1.333±0.866	0.799 <sup>a</sup>	0.014* <sup>a</sup>	0.536 <sup>a</sup>
MON 72 h	1.111±0.782	0.777±0.667	1.111±0.601			

**Table 5.** Effect of 60 Hz ELF-EMFs on haematological parameters of male BALB/c mouse strain in a prolonged (chronic) exposure of 10 d/8 h daily to 2.0 mT ELF-EMFs and negative (-) controls (sham-exposed animals). (a) In the cases of non-normal data distribution, the non-parametric Wilcoxon *t*-test was applied. TPP and HB were measured in g/dL, and cell counts were expressed as percentages.

Studied parameters	Mean $\pm$ SD		<i>p</i>	
	Sham control (-)	MMC control (+)	Sham control (-)	Chronic exposure
TPP 0 d	6.111 $\pm$ 1.621	6.767 $\pm$ 0.943	0.137	0.06
TPP 10 d	7.267 $\pm$ 1.510	7.622 $\pm$ 0.850		
HB 0 d	15.89 $\pm$ 1.244	16.06 $\pm$ 0.464	0.236	0.357
HB 10 d	15.33 $\pm$ 0.559	15.78 $\pm$ 0.755		
NEU 0 d	38.44 $\pm$ 8.779	26.89 $\pm$ 8.695	0.112	0.228
NEU 10 d	47.56 $\pm$ 13.72	31.44 $\pm$ 6.560		
EOS 0 d	0.111 $\pm$ 0.333	0.000 $\pm$ 0.000	1.0 <sup>a</sup>	0.332 <sup>a</sup>
EOS 10 d	0.111 $\pm$ 0.333	0.111 $\pm$ 0.333		
BAS 0 d	0.000 $\pm$ 0.000	0.000 $\pm$ 0.000	0.347 <sup>a</sup>	1.0 <sup>a</sup>
BAS 10 d	0.111 $\pm$ 0.000	0.000 $\pm$ 0.000		
LYM 0 d	63.67 $\pm$ 10.873	76.67 $\pm$ 8.775	0.163	0.066
LYM 10 d	55.33 $\pm$ 13.23	68.67 $\pm$ 10.120		
MON 0 d	0.978 $\pm$ 0.502	1.444 $\pm$ 1.130	0.081	0.199
MON 10 d	1.38 $\pm$ 0.410	0.844 $\pm$ 0.726		

EMF exposure may induce morphological changes in red blood cells, such as variations in size and shape.

Regarding the long-term exposure of 10 days/8 h daily, our results agreed with a previous investigation by ZHANG et al. (2020), but they used a longer (24-weeks) exposure to 50-Hz EMFs at 30  $\mu$ T, 100  $\mu$ T, and 500  $\mu$ T, and no significant effects on rats' haemograms were observed.

The observed changes induced by ELF-EMFs in blood indices are debatable but may be related to changes in blood biochemistry, as has been reported (PEIGHAMBARZADEH & TAVANA 2017, GHADHBAN 2020). In contrast, TOUITOU et al. (2013) and HASANA et al. (2021) did not observe a relationship between blood-cell indices and blood biochemistry. Moreover, the alterations in haematological indices may be attributed to apoptosis induced by ELF-EMFs (TOFANI 2022). However, a definitive answer on this topic has not been given yet (BARATI et al. 2021).

Even though the mechanism of action for cell cycle progression induced by ELF-EMFs has not yet been elucidated, reports have shown intrinsic electrical features associated with biostructures and biological functions such as development, growth, and repair. Furthermore, living organisms are sensitive to external electromagnetic fields of very weak intensities, which may be debatable. Based on the ongoing discussion and the above-mentioned facts,

more studies are needed to fully understand this phenomenon.

Regarding the rise in the percentage of neutrophils, it has been proposed that ELF-EMFs may act as a possible external factor that may modulate innate and/or adaptive immunity (PISZCZEK et al. 2021). PISZCZEK et al. (2021) have reported the bio-effects evoked by ELF-EMFs in particular immune cell types involved in different immune responses with the standard mechanical models and mainly activated intracellular signalling cascade pathways. Thus, one of these mechanisms may be involved in the increased neutrophil number observed in the current research.

In conclusion, our *in vivo* study suggests that ELF-EMF acute exposure decreased LYM number and increased TPP and NEU blood parameters. An advantage of the current study is that blood parameters were analysed in the same animal before and after treatment because the physiological state of a biological system is crucial to its response to potentially adequate electromagnetic exposure.

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