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Bioelectrochemistry and Bioenergetics 35 (1994) 29–32

The influence of extremely low-frequency variable magnetic fields on rheologic and dielectric properties of blood and the water–electrolyte balance in experimental animals

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Keywords: Variable magnetic fields; Rheologic properties; Dielectric properties; Blood; Water–electrolyte balance

1. Introduction

The theoretical considerations and results of experimental studies are indicative of the influence of variable magnetic field on structural and functional properties of biological membranes [1–3].

The aim of the study was to analyse the effect of extremely low-frequency (ELF) magnetic fields on some physiological processes depending on the status of cellular membranes in experimental animals. In the first experiment the changes of rheologic and dielectric properties of blood in animals exposed to variable magnetic field were investigated. In the second, the influence of repeated exposure to such fields on the water–electrolyte balance in laboratory animals was estimated.

2. Experimental details

The first experiment was carried out on 30 male guinea pigs weighing 280–320 g. 15 animals comprised a group exposed to the field, the other 15 animals made up a control group, in which sham exposure was carried out. All animals were housed in a reverse 12 h–12 h light–dark cycle with free access to standard laboratory food and water. A variable magnetic field (rectangular shape of impulse; frequency, 10 Hz, induction, 10 mT) was used. The whole body of each animal was placed in a specially designed chamber inside an applicator and exposed to the field for 30 min daily for 15 consecutive days. After the end of the experiment the blood was collected from the right heart ventricle of animals in aether anaesthesia with the use of anticoagulant. Immediately after blood collecting in the samples of obtained blood and serum, measurements of haematocrit and rheologic examination were made at a temperature of 310 K. The estimation of the viscosity of whole blood was made by means of a low gradient viscosimeter ("low shear" 100 Contraves), at shearing velocities $D_1 = 0.116\ \mathrm{s}^{-1}$ and $D_2 = 4.59\ \mathrm{s}^{-1}$. The viscosity of serum was estimated using Ubbelohd's microviscosimeter. Haematocrit was determined with the use of the microhaematocrit method. On the basis of a regression apparent viscosity–haematocrit equation the apparent viscosities for haematocrit 41% were estimated.

The other samples of blood were immediately placed into a specially designed measuring chamber. The values of impedance and phase shift angle were measured by means of impedancemeters in the frequency range from 100 to 10000 kHz [4]. The values of specific electrical conductivity χ and relative permittivity ϵ' were calculated on the basis of obtained data with the use of a specially developed computer program.

The second experiment was carried out on 105 male guinea pigs (220–250 g body weight). The animals were divided into two groups exposed to magnetic fields of different parameters (35 animals each) and a control group in which sham exposure was carried out. All animals were housed in optimal climate conditions with free access to food and water. Guinea pigs of the first group were exposed to a magnetic field of rectangular impulse shape, frequency 20 Hz and induction 8 mT, 1 h a day for 21 days. The animals of the second group were exposed to a field of sinusoidal impulse shape, frequency 40 Hz and induction 4.5 mT, 24 min a day also over a period of 21 days. After the end of the

SSDI 0302-4598(94)01746-8

Table 1
The mean values of whole blood viscosity, serum viscosity and haematocrit in both groups including statistical verification

Parameter under examination	Group exposed to magnetic field $x \pm SD$	Control group (unexposed) $x \pm SD$
Apparent blood viscosity η_{D_1} (mPa s)	35.9 ± 10.1 *	22.5 + 8.6
Apparent blood viscosity η_{D_2} (mPa s)	8.9 ± 1.16 **	7.00 ± 1.15
Serum viscosity η_0 (mPa s)	1.144 ± 0.033 ***	1.094 ± 0.029
Haematocrit Ht (%)	43.6 ± 1.4 **	40.7 ± 1.9

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.
SD, standard deviation.

experiment all animals were exsanguinated in ether anaesthesia. In the obtained blood the morphology was evaluated [5] and the levels of total protein, Na^+, K^+, Ca^{2+} and PO_4^{2-} were estimated by means of an automatic analyser [5–7].

The results of both experiments were treated statistically using Student's t test.

3. Results

The mean values of whole blood and serum viscosities as well as haematocrit with statistical evaluation are presented in Table 1.

A significant increase of whole blood viscosity measured at shearing velocity D_1 was observed in exposed animals ($\eta_{D_1} = 35.9 \pm 10.1$ mPa s, $\eta_{D_2} = 8.9 \pm 1.2$ mPa s) as compared to the controls ($\eta_{D_1} = 22.5 \pm 8.6$ mPa s, $\eta_{D_2} = 7.6 \pm 1.1$ mPa s). Significant differences between the two groups were also obtained in serum viscosity. A significant increase of serum viscosity ($\eta_0 = 1.14 \pm 0.033$ mPa s) and haematocrit (Ht = 43.6% ± 1.4%) were also obtained in animals exposed to a magnetic field, as compared to the controls ($\eta_0 = 1.09 \pm 0.039$ mPa s and Ht = 40.7% ± 1.9% respectively).

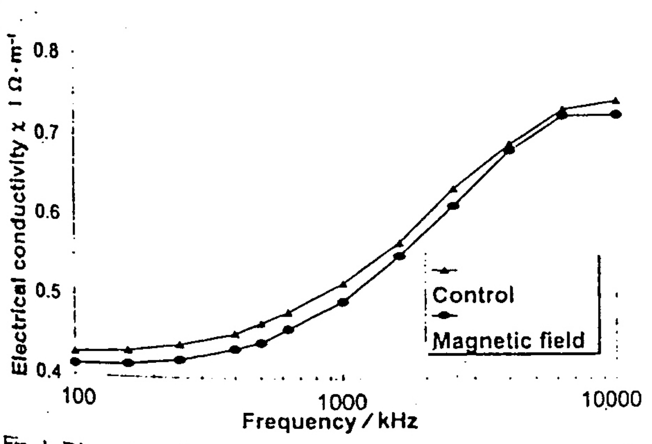

Fig. 1. Dispersion of specific electrical conductivity in blood samples with parameters nearing the mean values in both groups of animals.

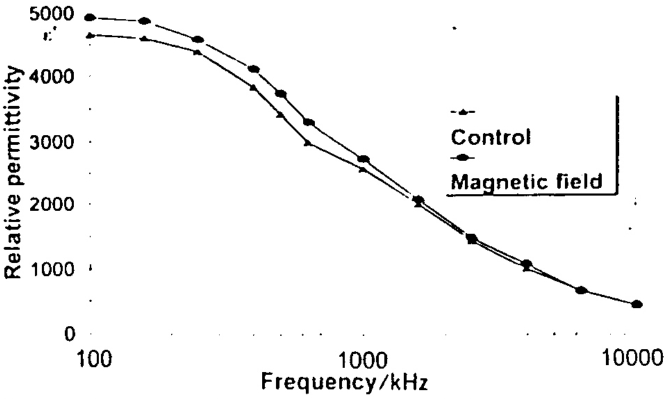

Fig. 2. Dispersion of relative permittivity in blood samples with parameters nearing the mean values in both groups of animals.

The dispersion of χ and ϵ' values for blood samples, with parameters nearing the mean values in both groups, are depicted in Fig. 1 and Fig. 2 respectively.

A distinct decrease of χ values was obtained in the blood of exposed animals at all frequencies, as compared to the controls. At the same time a distinct increase of ϵ' values in the frequency range from 100 to 1000 kHz was observed, as compared to the controls. No changes in relaxation frequency f_r were noticed between the two groups (Table 2). Mean values of χ estimated at relaxation frequency f_r in the blood of exposed animals (0.5593 ± 0.273 W^{-1} m^{-1}) were significantly lower as compared to the controls (0.5821 ± 0.0254 W^{-1} m^{-1}) (Table 2). Mean values of ϵ' estimated at relaxation frequency f_r in the blood of irradiated animals (2006 ± 147) showed no statistically significant differences as compared to the controls (1909 ± 132 (Table 2).

The mean values of concentration of some biochemical parameters of blood in both the exposed groups and the control one are presented in Table 3, while the mean values of some morphological parameters of blood in all groups of animals are presented in Table 4.

The significant decrease of erythrocyte count, haemoglobin, calcium and protein concentration, and also the increase of volume index (mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC)) were observed in both exposed groups as compared to the control one. The obtained

Table 2
The mean values of specific electrical conductivity χ and relative permittivity ϵ' estimated for relaxation frequency f_r and mean values of this frequency in both groups of animals with statistical evaluation

	Electrical conductivity $\chi \pm SD$ (Ω^{-1} m^{-1})	Relative permittivity $\epsilon' \pm SD$	Relaxation frequency $f_r \pm SD$ (kHz)
Control group	0.5821 ± 0.0254	1909 ± 132	1379 ± 157
Exposed group	0.5593 ± 0.0273 *	2006 ± 147	1351 ± 164

* $p < 0.05$.

Table 3
The concentration of some biochemical parameters of blood in both the exposed groups and the control one

	Control group	Exposed group I	Exposed group II
Protein (g l^{-1})	59.2	52.6 *	49.15 *
Sodium (mmol l^{-1})	136.4	136.2	134.3 *
Potassium (mmol l^{-1})	5.80	5.90	6.05
Calcium (mmol l^{-1})	2.71	2.40 *	2.35 *
Phosphates (mmol l^{-1})	2.34	2.54	2.28

* Statistical significance $p < 0.05$.

Table 4
The values of some morphological parameters of blood in both the exposed groups and the control one

	Control group	Exposed group I	Exposed group II
Haematocrit (%)	40.3	35.9 *	37.4 *
Haemoglobin (mmol l^{-1})	8.43	7.75 *	7.84 *
Erythrocytes (T l^{-1})	4.49	4.02 *	4.18 *
MCV [a] (fl)	89.2	89.5	89.6
MCH (fmol)	1.87	1.93 *	1.88
MCHC (mmol l^{-1})	20.9	21.6 *	21.0

* Statistical significance $p < 0.05$.
[a] MCV, mean corpuscular volumen.

results seem to be indicative of the formation of hypotonic hyperhydration and hypocalcaemia, as a result of exposure of guinea pigs to variable magnetic field.

4. Discussion

The results of the first experiment prove a distinct effect of variable magnetic field on rheologic properties of blood in experimental animals. The increase of viscosity of the blood might be related to structural (modification of the liquid crystalline structure of membranes) and functional (changes in enzymatic activity of the membrane ion pumps) changes of cell membranes resulting in a decrease of aggregation of erythrocytes [1,3,8] and dislocation of body fluids (leading to the increase of haematocrit) [2,3,9]. The increase of serum viscosity might be attributed to changes in the proportions of lipid and protein fractions of serum [2,3,9–11]. The other mechanism of this action of a magnetic field is probably related to the increase of intrisic friction in the electrolytic and colloidal structures of the organism as a result of ion dislocation [3,9].

The obtained data confirm also a distinct effect of variable magnetic field on the dielectric properties of blood in experimental animals. Since the observed changes in χ and ϵ' occurred in the β dispersion region, they might therefore be attributed to the charging of cell membranes in erythrocytes and affecting serum colloids [12,13]. The mechanisms of the observed effect are probably also related to the influence of the magnetic field on ion permeability and the capacitive reactance of the membrane due to changes of its lipid, liquid crystalline structure and enzymatic activity of ion pumps dependent on adenosine triphosphate (ATP-ase). The other mechanisms might be attributed to the changes of ion concentration on both sides of the cell membrane as a result of the Lorentz force (Hall effect) and producing electric tension in colloidal structures of the organism under the influence of a magnetic field [1–3].

Some of the above-mentioned mechanisms, especially related to the structural and functional changes of biological membranes and changes of serum protein fractions, might also explain the results of the second experiment. The changes of the liquid crystalline structure of the cellular membranes and inhibition of Na^+/K^+ ATP-ase result in changes of ion permeability and disturbances of body fluids volume [1,3,14,15]. The characterization of these changes is probably related to the parameters of the field and this might explain the different tendency in changes of haematocrit in the two experiments.

The modification of calcium canals of membranes under the influence of a magnetic field leads to penetration of calcium ions inwards on the cells resulting in hypocalcaemia which was observed in the experiment [3,14,16,17].

5. Conclusions

(1) The ELF variable magnetic field causes in experimental animals a modification of rheologic and dielectric properties of blood in the form of increases of serum and blood viscosity, a decrease of specific electrical conductivity and an increase of relative permittivity of the blood.
(2) The repeated exposure of experimental animals to ELF variable magnetic field results in disturbances of the water–electrolyte balance in the form of hyperhydration and hypocalcaemia.
(3) The results of the study might confirm indirectly the incidence of cellular membrane changes in the mechanism of the biological effect of ELF variable magnetic fields.

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