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Effects of Electromagnetic Pulse on Serum Element Levels in Rat

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Abstract Electromagnetic pulse (EMP) was a potentially harmful factor to the human body, and a biological dosimetry to evaluate effects of EMP is necessary. Little is known about effects of EMP on concentration of macro and trace elements in serum so far. In this study, Sprague-Dawley rats were randomly divided into 50-kV/m EMP-exposed group (n=10), 100-kV/m EMP-exposed group (n=10), 200-kV/m EMP-exposed group (n=40), and the sham-exposed group (n=20). The macro and trace element concentrations in serum were examined at 6, 12, 24, and 48 h after EMP exposure at different electric field intensities. Compared with the sham-exposed groups, the concentration of sodium (Na), potassium (K), magnesium (Mg), calcium (Ca), zinc (Zn), copper (Cu), iron (Fe), selenium (Se), and manganese (Mn) in rat serum was not changed significantly within 48 h after 200 pulses of EMP exposure at electric field intensity of 50, 100, and 200 kV/m although the K level was decreased and the Ca level was increased with the electric field intensity of EMP increasing. In addition, there was a tendency that the Zn level was decreased with the time going on within 48 h after EMP exposure. Under our experimental conditions, EMP exposure cannot affect the concentration of macro and trace elements in rat serum. There was no time–effect or dose–effect relationship between EMP exposure and serum element levels. The macro and trace elements in serum are not suitable endpoints of biological dosimetry of EMP.

Keywords Electromagnetic pulse · Element · Rat · Serum

Abbreviations

EMP	Electromagnetic pulse
Na	Sodium
K	Potassium
Mg	Magnesium
Ca	Calcium
Zn	Zinc
Cu	Copper
Fe	Iron
Se	Selenium
Mn	Manganese
GTEM	Gigahertz transverse electromagnetic

Introduction

Electromagnetic pulse (EMP) is a short- and high-voltage pulse with an extremely fast rising time and characterized by a broad bandwidth. With the development of electromagnetic technology, EMP is extensively used in many fields such as military campaigns, security screening, and medical applications. The increasing opportunity of EMP exposure has raised concerns regarding the biological effects and potential health hazard of EMP on humans. The previous studies of our department reported that there was a link between EMP exposure and various adverse effects on the nervous system [1–3] and reproductive system [4, 5]. This indicates that EMP we used is a potentially harmful factor to the human body, and a biological dosimetry to evaluate effects of EMP is

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necessary. However, there was no information about biological dosimetry of EMP available so far. To find an important endpoint of biological dosimetry of EMP, parameter in serum is possibly a good choice because it is convenient and almost atraumatic to obtain and evaluate.

Macro and trace elements are important for metabolism of tissues and normal growth of living organisms [6]. For example, sodium (Na) and potassium (K) play critical role in transmission of nerve impulses through action potentials and influencing osmotic balance between cells and the interstitial fluid with their distribution mediated in all animals by the so-called Na^+/K^+-ATPase pump. Magnesium (Mg) is involved in manipulating important biological polyphosphate compounds like ATP, DNA, and RNA. As a major material used in mineralization of bone, teeth, and shells, calcium (Ca) is the most abundant metal by mass in many animals. The Ca ion has a basic function in neurotransmitter secretion, oxidative stress, and apoptosis [7, 8]. Zinc (Zn) is a needed factor for DNA synthesis, RNA transcription, cell division, and cell activation [9]. Copper (Cu) is a key constituent of the respiratory enzyme complex cytochrome c oxidase. Zn and Cu protect against oxidation by acting as cofactors for antioxidant enzymes such as superoxide dismutase and catalase [10]. Iron (Fe) plays an important role in forming complexes with molecular oxygen in hemoglobin and myoglobin, and it is used at the active site of many important redox enzymes dealing with cellular respiration and oxidation and reduction in animals. Selenium (Se) is a component of the antioxidant enzymes including glutathione peroxidase and thioredoxin reductase. Manganese (Mn) is essential for immune system functioning, regulation of blood sugars and cellular energy, bone growth, defense against free radicals, and, together with vitamin K, supports blood clotting [11]. Critical molecular events within the cell such as gene expression, cell proliferation, nerve conductance, oxygen transport, and cell death are affected by macro and trace elements [12]. So, it is reasonable that the effects of EMP on the human body might lead to the changes of macro and trace element concentrations. And some researchers have already reported that electromagnetic field could affect macro and trace element levels in different organs such as the brain, kidney, and testis [13–15]. However, there were insufficient reports about the effects of EMP on macro and trace elements in serum, and the results were contradictory until now. Therefore, the objectives of the present study were to assess whether EMP causes any variations on macro and trace element concentrations in serum and to explore the dose–response relationship to search for an endpoint of biological dosimetry of EMP. In the current study, Sprague-Dawley rats were exposed to EMP at different electric field intensities, and the macro and trace element concentrations in serum were examined at different time points after EMP exposure.

Materials and Methods

Animals

Eighty 260–340-g Sprague-Dawley adult healthy male rats were purchased from the Experimental Animal Center of the Fourth Military Medical University (Xi'an, China). The ambient temperature and relative humidity of the animal room were 21±1 °C and 60±7 %, respectively. The room was illuminated with artificial light for 12 h daily and was dark for 12 h at night. The animals were allowed free access to standard pelleted food and tap water. All studies were performed with the approval of the experimental animal care committee of the Fourth Military Medical University.

Groups

Rats were randomly divided into four groups: 50-kV/m EMP-exposed group (n=10), 100-kV/m EMP-exposed group (n=10), 200-kV/m EMP-exposed group (n=40), and the sham-exposed group (n=20). Samples from ten (for 200-kV/m EMP-exposed group) or five (for the sham-exposed group) rats were respectively collected at 6, 12, 24, and 48 h after EMP exposure.

EMP Exposure

The EMP exposure device was described by Li et al [16]. Briefly, the EMP (peak intensity 200 kV/m, rise time 10 ns, pulse width 350 ns, 0.5 Hz, 200 pulses total) was generated by a spark gap pulse generator and transmitted into a gigahertz transverse electromagnetic (GTEM) cell (Fig. 1). The EMP simulator comprised four parts: generator, GTEM cell, operation box, and field intensity monitor. Both EMP generator and GTEM cell were devised by the Department of Mechanical Engineering at Southeast University (Nanjing city, Jiangsu province, China). In order to observe the dose–response of EMP exposure, the rats were divided into different groups and were exposed or sham-exposed to EMP for 200 pulses at the

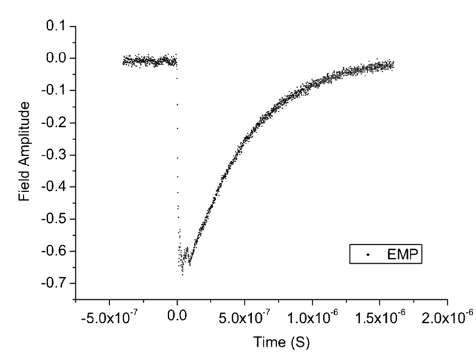

Fig. 1 Wave form of EMP. The EMP (peak intensity 200 kV/m, rise time 10 ns, pulse width 350 ns, 0.5 Hz) was generated by a spark gap pulse generator and transmitted into a GTEM cell

electric field intensity of 50, 100, and 200 kV/m, respectively. During exposure, the rats were placed in a special plastic box (50 cm×40 cm×30 cm). No metallic parts were used and the rats were able to move freely in the box. The rats in the sham-exposed group were placed in the similar exposure chamber under identical conditions for the same interval, but they were not exposed to EMP. After exposure, no significant change occurred in colonic temperature.

Measurement of Macro and Trace Elements

At 6, 12, 24, and 48 h after EMP exposure, rats of each group were anesthetized with 40 mg/kg i.p. of sodium pentobarbital, and 3 mL of the blood samples were collected from carotid artery in tubes washed with acid for the macro and trace element analysis. After centrifugation at 1,800×*g* for 10 min at 4 °C, serum was removed and aliquots were kept frozen at –20 °C for the macro and trace element analysis. The levels of macro and trace elements in the serum were determined by an atomic absorption spectrophotometer (180-80, Hitachi, Japan) equipped with an air-acetylene flame burner and hollow-cathode lamps. The wavelengths were 589, 766.5, 285.2, 422.7, 213.9, 324.8, 248.3, 196, and 279.5 nm for Na, K, Mg, Ca, Zn, Cu, Fe, Se, and Mn, respectively. The spectral bandwidth was 0.5 nm. The standard stock solutions for the trace elements were obtained from Sigma. The standard solutions and samples were diluted in double-distilled water. The variation coefficient for all elements was <5 %.

Statistical Analysis

Mean values and standard deviations were calculated, and statistical significance of the differences between treatments was evaluated using a computer program (SPSS 13.0, SPSS Inc., Chicago, IL, USA). Data were analyzed by Kruskal–Wallis one-way analysis of variance and Bonferroni-corrected Mann–Whitney *U* tests, with $p<0.05$ as the criterion for significance in all statistical comparisons.

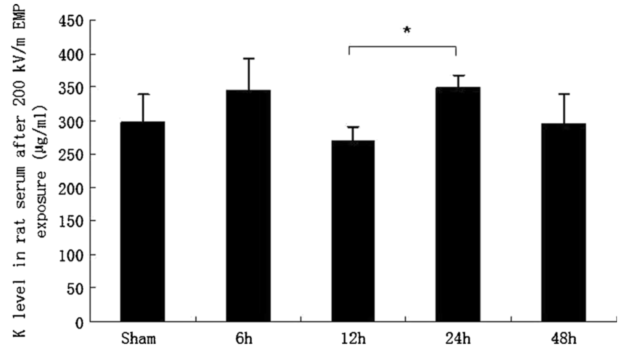

Fig. 2 K level in rat serum at different time points after 200-kV/m EMP exposure. *$p<0.05$

Results

Time–Effect Relationship Between EMP Exposure and Macro Element Levels in Rat Serum

As shown in Table 1, the level of Na, K, Mg, and Ca in rat serum fluctuated at 6, 12, 24, and 48 h after 200-kV/m EMP exposure for 200 pulses, but none of these macro elements changed significantly compared with that in the sham-exposed group ($p>0.05$). The K level in 24-h EMP-exposed group was significantly higher than that in 12-h EMP-exposed group (Fig. 2, $p<0.05$).

Time–Effect Relationship Between EMP Exposure and Trace Element Levels in Rat Serum

There was no significant difference in the level of Zn, Cu, Fe, Se, and Mn in rat serum between the sham-exposed group and the EMP-exposed group at each time point (6, 12, 24, and 48 h) after 200-kV/m EMP exposure for 200 pulses. Although a tendency could be seen that the Zn level was decreased with the time going on within 48 h after EMP exposure, the difference was not statistically significant (Table 2, $p>0.05$).

Table 1 Macro element level in rat serum after 200-kV/m EMP exposure (mean±SD)

Element (μg/ml)		Time after EMP exposure			
	Sham (*n*=20)	6 h (*n*=10)	12 h (*n*=10)	24 h (*n*=10)	48 h (*n*=10)
Na	2,429.87±233.12	2,442.02±861.23	2,326.22±277.64	2,458.18±66.57	2,266.52±237.18
K	296.54±43.34	342.86±50.54	269.55±20.74	347.31±18.91*	295.51±44.82
Mg	27.35±4.43	29.11±1.77	27.51±2.08	30.23±2.10	25.15±3.59
Ca	113.65±31.92	121.31±16.02	137.85±51.98	122.27±0.95	101.33±16.60

*$p<0.05$ vs 12 h

Table 2 Trace element level in rat serum after 200-kV/m EMP exposure (mean±SD)

Element (μg/ml)	Time after the exposure to EMP				
	Sham (n=20)	6 h (n=10)	12 h (n=10)	24 h (n=10)	48 h (n=10)
Zn	1.43±0.21	1.32±0.44	1.15±0.28	1.06±0.16	1.00±0.14
Cu	0.61±0.13	0.72±0.08	0.71±0.12	0.63±0.15	0.83±0.26
Fe	1.54±0.34	1.13±0.90	1.47±0.41	1.40±0.25	1.33±0.38
Se	0.41±0.11	0.45±0.05	0.44±0.07	0.39±0.13	0.43±0.09
Mn	0.23±0.06	0.19±0.03	0.24±0.05	0.19±0.09	0.21±0.07

Table 4 Trace element level in rat serum 12 h after EMP exposure (mean±SD)

Element (μg/ml)	Field intensity			
	Sham (n=20)	50 kV/m (n=10)	100 kV/m (n=10)	200 kV/m (n=10)
Zn	1.43±0.21	1.12±0.17	1.20±0.20	1.15±0.28
Cu	0.61±0.13	0.78±0.17	0.71±0.24	0.71±0.12
Fe	1.54±0.34	1.69±0.23	1.60±0.07	1.47±0.41
Se	0.41±0.11	0.35±0.09	0.40±0.12	0.44±0.07
Mn	0.23±0.06	0.26±0.05	0.21±0.08	0.24±0.05

Dose–Effect Relationship Between EMP Exposure and Macro Element Levels in Rat Serum

Compared with the sham-exposed group, the level of Na and Mg in rat serum was not significantly altered 12 h after EMP exposure for 200 pulses at the electric field intensities of 50, 100, and 200 kV/m. Also, there was no significant difference in the level of K and Ca in rat serum between the sham-exposed group and the EMP-exposed group although the K level was decreased and the Ca level was increased with the increasing of electric field intensity of EMP (Table 3, $p>0.05$).

Dose–Effect Relationship Between EMP Exposure and Trace Element Levels in Rat Serum

Table 4 shows that there were no significant changes in the level of Zn, Cu, Fe, Se, and Mn in serum 12 h after the rats were exposed to 50, 100, and 200 kV/m EMP for 200 pulses compared with that in the sham-exposed group ($p>0.05$). No tendency could be found in each of the trace element level after EMP exposure at different electric field intensities.

Discussion

Na and K are essential macro elements for the function of all living cells and are important in neuron function and osmoregulation between cells and the extracellular fluid. The previous reports in our laboratory showed that EMP may affect the nervous system [1–3], so we detected the concentration of Na and K in rat serum at different time points after EMP exposure at different electric field intensities. Our data showed that although the K level in 24-h EMP-exposed group was significantly higher than that in 12-h EMP-exposed group and showed a decreasing tendency with the electric field intensity of EMP increasing, there was no time–effect or dose–effect relationship between EMP exposure and trace element levels in rat serum. This indicated that the EMP we used in the current study was not strong enough to affect the level of Na and K in rat serum and Na and K in rat serum were not sensitive to electromagnetic field, which was also confirmed by some previous studies [17, 18].

Mg is also an essential macro element to all living cells, and it is an essential cofactor in 80 % of all cellular enzymes. Over 300 enzymes, including those involved in energy metabolism and reactive oxygen species production, require the presence of Mg ions for their catalytic action [19]. The previous reports about effects of electromagnetic exposure on Mg concentration in serum were conflicting. Bonhomme-Faivre et al. [17] found that no significant difference was observed in concentration of Mg in mouse serum after chronically exposed to low-frequency (50 μT, 50 Hz) electromagnetic fields. On the contrary, Burchard et al. [18] demonstrated that level of Mg in blood plasma decreased after 60 Hz extremely low-frequency electric (10 kV/m) and MF (30 μT) exposures in dairy cows for 30 days. In the current study, we found that the Mg level in rat serum did not change significantly 6, 12, 24, and 48 h after EMP exposure at electric field intensities of 50, 100, and

Table 3 Macro element level in rat serum 12 h after EMP exposure (mean±SD)

Element (μg/ml)	Field intensity			
	Sham (n=20)	50 kV/m (n=10)	100 kV/m (n=10)	200 kV/m (n=10)
Na	2,429.87±233.12	2,426.32±305.82	2,323.95±676.96	2,326.22±277.64
K	296.54±43.34	294.35±32.24	287.64±90.35	269.55±20.74
Mg	27.35±4.43	25.17±2.72	25.56±6.03	27.51±2.08
Ca	113.65±31.92	114.03±23.46	128.42±41.51	137.85±51.98

200 kV/m. No dose–response relationship available. The reason of the difference between results may be due to the different frequencies or intensities of electromagnetic field used in different studies.

Ca is another macro element which is essential for living organisms, in particular in cell physiology, where movement of the Ca ion into and out of the cytoplasm functions as a signal for many cellular processes. As for the concentration of Ca in serum, early studies noted that it did not change after electromagnetic exposure [17, 18]. This is consistent with our current result which also showed that no significant difference was observed in Ca concentration in rat serum at different time points after EMP exposure at different electric field intensities although the Ca level was increased with the electric field intensity of EMP increasing. Because the peak electric field intensity of the applied EMP in this study is 200 kV/m, we could not detect the Ca level after EMP exposure at electric field intensity higher than 200 kV/m. However, according to our results, it is interesting to study the effects of electromagnetic field with higher electric field intensity on Ca level in serum in future study.

Zn, Cu, Fe, Se, and Mn are important trace elements in the body. It is reported that the levels of these trace elements could be affected by some physical factors such as X-ray [20] or light [21]. As for the effects of electromagnetic field on trace element level in serum, the previous results were contradictory. Burchard et al. [18] demonstrated that level of Zn, Cu, Fe, and Mn in blood plasma did not change after 60 Hz extremely low-frequency electric (10 kV/m) and MF (30 μT) exposures in dairy cows for 30 days. Akdag et al. [22] exposed Sprague-Dawley rats to 50 Hz of extremely low-frequency magnetic fields (1.35 mT) 2 hr/day for 2 months (7 days a week), but no statistically significant alteration was observed in the serum concentrations of Cu, Zn, and Fe except in Mn concentration. Ghodbane et al. found that static magnetic field exposure failed to alter the plasmatic selenium concentrations in rats [23]. In the present study, we found that there were no significant changes in the level of Zn, Cu, Fe, Se, and Mn in rat serum 6, 12, 24, and 48 h after 200-kV/m EMP exposure for 200 pulses at electric field intensities of 50, 100, and 200 kV/m. However, there was a tendency that the Zn level was decreased with the time going on within 48 h after EMP exposure, although the difference was not statistically significant. It might be that 48 h after the EMP exposure was not long enough to show the significant decrease of Zn level in serum. Because Zn plays a critical role in biological membrane stabilization, protein synthesis, and nucleic acid metabolism as well as in the growth of normal tissue [24, 25], further detection on Zn level in serum at longer time after EMP exposure is still of considerable interest, as they may reveal the significant Zn-related effects of EMP.

In conclusion, 200 pulses of EMP exposure at electric field intensities of 50, 100, and 200 kV/m could not affect concentration of Na, K, Mg, Ca, Zn, Cu, Fe, Se, and Mn in rat serum within 48 h. There was no time–effect or dose–effect relationship between EMP exposure and macro and trace element level in rat serum that could be found, and these elements are not suitable endpoints of biological dosimetry of EMP. It is needed to explore the longer time effects of EMP on Zn concentration in serum in future study.

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Conflict of Interest The authors indicate no potential conflicts of interest.

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