

RESEARCH ON BIOLOGICAL RESPONSES RELATED TO THE EFFECTS OF EXTREMELY LOW FREQUENCY ELECTRIC FIELDS

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Abstract: A device named Healthtron approved in Japan by the Ministry of Health and Welfare 40 years ago that stimulates the human body by exposing it to an electric field has been produced and marketed ever since to alleviate complaints such as headaches, stiff neck, insomnia and chronic constipation. In this paper we outline research in the last decades on the effects and the action mechanism by which electric fields stimulate the body.

Key words: Electric-field stimulation, headache, stiff neck, insomnia, chronic constipation, lower back pain, and homeostasis.

1. Introduction

Indefinite complaint, such as headache and fatigue, of workers under the high electric field has been reported in the 1960's in the former USSR. Studies on the risk of electric field on the health hazard have been conducted since caution for persons working in the high electric field was requested at the CIGRE (Conference International des Grands Reseaux Electriques a haute tension) in 1972.

T. Takagi et al. of Japan reported in 1970 on changes of heart rate and transitional change of the blood pressure in the electro-static induction by a 500V power transmission line.

A consensus has been reached at the U.S.-Japan Seminar held in 1988 in Hawaii that the possible risk of the electric field on the health hazard is extremely low.

The risk study has moved from the electric field to the magnetic field since 1979 when Wertheimer reported the epidemiological investigation on the relationship between the magnetic field strength at residences near power distribution stations and the incidence rate of the child leukemia.

Then, a large number of studies including the epidemiological surveys were actively conducted for about 20 years in the world on the effect of magnetic field on human bodies, animals and cells. However, no experimental verification for health hazard to endorse the epidemiological investigation has been found.

On the other hand, the positive application of the electromagnetic radiation and the electromagnetic field has been studied and commercialized, including the therapy equipment with the microwave, the low-frequency electric therapy equipment, and hyper-

thermia equipment. However, examples of positive study toward the health by the electric field alone are very few at present.

2. Research back ground for beneficial effects

The history of positive research in Japan on the beneficial effects of electric fields goes back to the middle of the 18th century. In 1776, a Japanese scholar, G. Hiraga succeeded in repairing a broken friction generator, and named it Elekiteru. He used the device on patients, in the belief that the electricity would alleviate pain.

150 years later, T. Hara, who was interested in a method of healing using a Wimshurst electrostatic generator machine, invented a unique high frequency electro-potential therapy device in 1928. It was the time when physico-therapeutics were at their height of popularity before the availability of antibiotic drugs. The device was welcomed by tuberculosis patients and later leper patients for its effectiveness in alleviating symptoms such as fatigue. The device was later used for hypertensive patients and to treat gastritis etc.

In 1964, electro-potential therapy apparatus was made officially approved in Japan for the first time by the Ministry of Health and Welfare. It was firstly in the form of electrical appliances produced and marketed for clinics and secondly it has been put to practical use for 40 years to alleviate complaints such as headaches, stiff neck, insomnia and chronic constipation.

F. Ito et al. conducted research in 1981 on the effects of electric fields on volunteer patients exposed to 30kV (nearly 15kV/m) for 15 minutes, 1-3 times per week. They suggested that the percentage change in systolic blood pressure, defined as the rate of the reduction in blood pressure over the initial blood pressure, was positively correlated with the rennin ratio. The closer the relationship of blood pressure to a sympathetic nerve with high rennin, the more notable the percentage change. Three of six patients with mild pituitary hormone deficiency demonstrated symptomatic improvements together with the normalization of endocrinological disturbances such as urine 17-OHCS, urine 17-KS, plasma cortisol and ACTH.

R.A. Jaffe et al. reported that the soleus muscle in rats exposed to a 60Hz, 100kV/m electric field for 30

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days recovered significantly faster than the sham exposure after the soleus was fatigued by 30Hz frequency stimulation of the sciatic nerve.

By radio-immunoassay, R. M. Hackman et al. studied plasma corticosterone concentration of mice exposed to 60Hz electric fields from 0kV/m to 50kV/m for periods ranging from five minutes to six weeks. They reported in 1981 that mice may perceive high-intensity electric fields and exhibit orientation reaction to such fields. It was also reported that the corticosterone values of mice exposed to electric fields exhibit a slight, transient increase and that the values were one-half to one-third the value of sound stress.

In the study of the dynamic properties of bone, I. Yasuda observed the piezoelectric effect in bone produced by electric field including electric current for the first time. In 1956, E. Fukada and I. Yasuda undertook quantitative measurement of the piezoelectric constants of bone by means of both direct and converse piezoelectric effects, and suggested that they were the action mechanisms of callus formation. Then, it was investigated by Lavine et al. and has been widely applied to the therapy of broken bones.

The therapy with the static electricity were applied in Europe and U.S. from 1800's. However, in many countries the development of the apparatus of field exposure has declined, because no enterprise has re-evaluated this under the 1976 re-evaluation system of medical equipment in U.S. It has been also declining in European countries in recent years.

Based upon up-to-date measuring technique of electric field and magnetic field, and rapid progress in the medical diagnostic techniques, we would like to introduce the study carried out in recent 10 years about the therapeutic device using electric field.

3. Methods and materials

3.1 Electric field exposure system for cells

Experiments on the electric field exposure to cells have been conducted by our co-researchers using the following three methods; 1) A plate with cultured cells was installed in a uniform electric field generated by plane parallel electrodes. It was placed in an incubator to maintain temperature, humidity and the concentration of carbon dioxide at constant levels; 2) A set of plane parallel electrodes were placed in the medium in a plate, and small electric current flew between them. Cells were planted on a filter which was not contact to the electrodes; and 3) Cells were contained in a cultivating case made of an insulating material. Plate electrodes were attached on both sides of the case and a strong electric field was generated by applying a voltage between the electrodes.

3.2 Electric field exposure system for small animals

Many types of electric field exposure systems for small animals have been developed, using parallel plates in U.S and Japan for the risk-study of the electric field. For development of the electric field exposure device, we established a concept of experiment under the conditions mentioned below. We constructed an exposure system named SYNTHESIS (Shimizu, Yoshioka, Takeuchi, Hakuju, Isaka, Suzuki), taking acronyms of the names of co-researchers who cooperated in the development of this device.

3.2.1 Concepts for SYNTHESIS

- a. To conduct laboratory experiments of electric field exposure to a small animal in a uniform electric field.
- b. To expose the animal in a conscious state with the restriction kept as small as possible.
- c. To expose only one animal in a cage at a time, so to avoid shielding of the electric field by a group of animals under the experiment.
- d. To make necessary provisions to reduce the stress as follows;
 - To avoid field exposure for such a long time that the water feed is required.
 - To reduce the stress caused by being enclosed alone in the cage by starting the experiment after habituation for 2 weeks.
 - To reduce the stress by placing the animal in the environment that allows the animal to run around and see the group.
 - Not to enclose in a cage with such a size that the animal can run around in order to avoid the audible noise that may cause stress.
- e. To construct the cage with such structure that the electric potential gradient can be maintained unchanged when the cage is contaminated.
- f. To conduct the experiment without electric discharge.
- g. To keep the temperature and humidity at constant.

3.2.2 Description of SYNTHESIS

The electrodes were made of a pair of plane plates of 1200 mm × 1200 mm. The upper electrode was electrically grounded. On the lower electrode the voltage of 50 Hz and 7kV - 11kV was applied using a stabilized power supply (Tokyo Seiden, CVFT1-200H) and a voltage transformer (Hakuju Institute for Health Science). The lower electrode was placed at 1 m above the floor and the upper electrode was mounted 400mm above it. We constructed a cage for a small animal using a cylinder made of acrylic resin (400 mm diameter, 400 mm height and 5 mm thickness). Openings were made by cutting two horizontal slits (174 mm wide, 3 mm high) separated vertically by 140 mm. Along the circular peripheral

of the cylinder, the two slits were shifted vertically by 10 mm at each central angle of 30 degree. As the result, the electric potential gradient was maintained along the cage surface and the variation of the electric field inside the cage could be kept minimal even when the cage surface was contaminated by the animal. The temperature and humidity were also kept at constant level by the air convection through the clearances of the slits and the wire netting on electrodes.

3.3 Electric field exposure system for human test

The experimental unit for exposure of human body to electric field was manufactured by the Hakuju Institute for Health Science Co., Ltd. Main components of the unit were the charging footrest (electrode under the feet), the grounded upper electrode, insulated chair for the therapy, an insulated step for the prevention of electric shock of patient, and a voltage transformer.

The voltage from the power line (50Hz/60Hz, 100V) was raised to 30 kV and was fed to the electrode installed in the footrest through a high impedance circuit for the safety. The electrode inside the footrest was covered with the acrylic resin with high volume resistance for electrical insulation.

We carried out a simulation to visualize the fields on the body surface and the current induced in the body using the technique developed by K. Shimizu prior to the design of commercial product.

After the completion of the design, the electric fields on the body surface and the induced currents in the body were measured and verified using the tool developed by K. Isaka. And then, the product was commercialized.

It was classified under the Class 2 of the risk classification of GHTF (Global Harmonization Task Force). The type and extent of protection from the electric shock were Class 1 and Type B, respectively. The therapeutic devices of the output voltage lower than 9kV in Japan were designed and manufactured in accordance to JIS C 9335-1 (in compliance to IEC 60335-1) and those of the output voltage between 10 kV and 30 kV in accordance to JIS T 1001 (in compliance to IEC 601).

4. Experimental methods and results

4.1. Cell proliferation

It was reported by H. Wakisaka and M. Yoshioka et al. that cells of the electric field exposure group tended to proliferate more than the sham exposure group by the experiment with the application of AC electric field of 50 Hz and 10 kV/m to HUVEC (Human Umbilical Vein Endothelial cells).

K. Isaka and S. Arase reported that, in the suppression of fibrocytes proliferation, a dose response relation was found at three different current densities of 10, 50 and 100 mA/m².

4.2 Calcium ions in cells

A group of M. Yoshioka reported that, when stimulating the HUVEC with ATP of 100 μ M/L, which is higher than the physiological concentration, the concentration of Ca²⁺ in the cell has significantly increased by the electric field exposure with 50Hz, 30 kV/m, induced current density 0.42 mA/m², compared with the sham exposure group.

4.3 Small animal experiments

N. Yago conducted the study described below between 1993 and 1997 under the contract from the Japan Home Health Apparatus Industrial Association. Based upon the results of the studies using small animals, the safety was confirmed in the case when the electric potential apparatuses (electric field exposure units for human approved in Japan) were used in the range of ordinary operation. The researchers concerning this study considered the possibility of beneficial effects to a human body as suggested as the relaxation after the use. The details of their study were the following.

- a. A sub acute toxicity study on the effect of 91 days repeated exposure on growth and water and food intake, ophthalmological examinations, urinalysis, hematological, blood chemistry examinations and histopathological observations of rats.
- b. A sub chronic toxicity and one-generation reproduction toxicity study in rats.
- c. Effects of exposure to an electric field on growth curves and tissue proliferation and cellular proliferation in rats.
 - c-1. Growth weight curve and tissue weights of total brain, heart, lung, liver, spleen, pancreas, kidney, adrenal gland, ovary and uterus.
 - c-2. Survival curves of Yoshida sarcoma - transplanted rats.
 - c-3. Tissue morphology of small and large intestines by haematoxylin-eosin staining and rate of bromodeoxyuridine incorporate.
 - c-4. Change in amounts of p53 mRNA in liver and lung.
- d. Effects of 7 days exposure to an electric field on blood pressure of spontaneously hypertensive rats and heart rate, levels of plasma catecholamine, plasma ACTH concentration, corticosterone.
- e. Effects of exposure to electric field on sleep-wake rhythm and sleep-fullness.
- f. Effects of electric field exposure on constipated rats caused by oral dose of morphine.

4.4 Human research results

M. Yamashita, et al. developed a telemetry technique to enable the measurement of EEG and ECG During the electric field exposure. They analyzed the EEG spectrum, heart rate variability, body temperature and blood pressure in the exposure with 30 kV therapeutic apparatus. Their report

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suggested the change in sympathetic nerve system, the decrease in skin temperature and the increased wake state of consciousness.

K. Isaka, et al. analyzed the data before, during and after the exposure with the 30kV therapeutic unit with healthy volunteers using a thermogram. They reported that the body surface temperature varied in 8 of 35 male subjects and in 5 of 21 female subjects with the tendency of reduction after the application. Any adverse effect was not found in the above two experiments.

4.5 Clinical research results

F. Ito, et al. measured the angles of stretch and bend of patients waist who visited the hospital for the acute low back pain. To evaluate the degree of back pain, a VAS (visual analogue scale) has been used. They reported that the patients received field exposure in addition to the ordinary therapy showed faster relief of pain than the patients with ordinary therapy alone.

F. Ito, et al. picked up patients with the complaint of stiff neck from those patients who visited the Clinic and measured the subjective symptom of stiff neck using VAS. It was found that the relief of stiff neck of the group with the electric field exposure added to the ordinary therapy was faster than the group with the ordinary therapy alone. In addition, they measured the blood volume in shoulder muscles using the infrared radiation, and confirmed that the blood volume increased after the electric field exposure. No adverse effect was found in these two clinical studies, endorsing the safety of above mentioned instruments.

5. Discussion and future trial

Based upon the results of these studies we have conducted after commercialization and the results of other studies in recent 10 years, the conclusions we reached are summarized as the following.

The animal bodies are responding to certain stimulation due to the electric field. It can be seen in the proliferation of cells, the increase of Ca^{2+} in cells, the change of internal secretion, such as the cortisol, the increased blood volume in human muscles, and

especially the dose response effect from 10 mA/m² to 100 mA/m².

To our regret, the mechanism which totally explain all the above phenomena has not been found in a strict sense. To understand the mechanism, we have to observe these phenomena as the reaction of our system in terms of homeostasis. We have to find out an objective variable to identify and to measure the biological effects as a dose-response relation.

Although it is not an easy task, we are continuing the study to support the effectiveness of this therapy. The telemetry techniques and optical techniques are promising tools to analyze the biological effects during the field exposure. With the help of these new techniques, we are conducting the research to clarify the biological responses through the various control systems of homeostasis.

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Fig.1 Synthesis



Fig.2 Mice in the cage