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Effects in Rodents of a 1-Month Exposure to Magnetic Fields (200-1200 Gauss)

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Under the conditions of the present study, magnetic fields ranging from 200 to 1200 Gauss strength have no toxic or histopathological effects on rats. The in vivo study and the histopathological results show no alterations of the vascular tissues, except for a nonpathological congestion of the spleen, and no intravascular thrombosis related to the experimental conditions. An unexpected observation was that the increase in body and organ weight of young rats was significantly greater in the groups exposed to magnetic fields. Therefore, no undesirable effects should be expected when magnetic fields within the prescribed safety limits of 200 to 2000 Gauss are applied to human subjects for several hours.

MAN HAS been exposed to magnetic fields in space travels (5,7,11) and in hydroelectric plants (4). Except for one Russian clinical report made by Kholodov (1) describing nonspecific vascular problems in workers subjected to magnetic fields in hydroelectric plants, there was no evidence that long term exposure to magnetic fields from 500 to 2000 Gauss induced any damaging effect in man. In animals, damage was reported only after prolonged exposure to magnetic fields exceeding 4000 Gauss (2).

As a result of these studies, the Stanford Line Accelator Center (SLAC) in California has recommended the following guidelines for limiting human exposure to magnetic fields (7):

—Extended periods (hours)
Whole body or head = 200 Gauss
Arms and hands = 2000 Gauss
—Short periods (minutes)
Whole body and head = 2000 Gauss
Arms and hands = 20000 Gauss

The aim of this study was to investigate the effects of continuous exposure to magnetic fields from 200 to 1200 Gauss, which are of a much smaller magnitude than those used by others (1,2). This investigation was prompted by the development of a new electromagnetic device, the Doll Arterial Flowgraph, designed to record in a noninvasive fashion pulsatile arterial flow of the limbs (8-9,11,15).

This instrument uses a magnetic field of 400 to 600 Gauss. We became concerned about the possible damaging effect on small blood vessels of the current induced by this field after studying the results reported by Sawyer *et al.* (16). These authors reported that small electric currents directly applied across the walls of small arteries will produce intravascular occlusion. We calculated that the voltage generated across the vessels in Sawyer's experiment was much larger than that which could be induced by the magnetic field applied by the Doll flowgraph or by magnetic fields encountered in space travels. However, a controlled and systematic study of the possible damaging effect on small vessels by magnetic fields was deemed necessary.

Two series of experiments were performed. In the first, microscopic observations were made of the capillaries of the mesoappendix of rats exposed for several weeks to a magnetic field of 500 Gauss. In the second, a systematic histopathological study of the vessels and the major organs of rats exposed to magnetic fields of 400 to 1200 Gauss for 1 month was performed.

MATERIALS AND METHODS

Housing of animals in magnetic fields: The magnets used in this experiment were placed in a frame built to fit around the cages where the animals were kept. The cages were then placed between the two magnets, in a median position so as to obtain a homogenous magnetic field around the cages. The fields obtained were 200, 400, 500, and 1200 Gauss. Three rats were placed in the same cage and given water and food *ad libitum*.

In vivo study of the small arteries of the rat omentum: Twelve rats were studied: three control rats and three groups of three rats exposed to 500 Gauss for 6, 12, and 30 d, respectively. After these exposures, the capillary circulation was observed in the mesoappendix according to the technique of Zweifach (19), using a microscope of 160x magnification. Special attention was given to the circulation of erythrocytes and their possible aggregation in the vessels, as described by Sawyer.

Histopathological and laboratory study: Four groups

of rats studied:

The length of exposure varied from 28 to 32 d. The rats

Group II = 200 Gauss; 2 males, 2 females
Group III 400 Gauss; 3 males, 3 females
Group IV 1200 Gauss; 3 males, 2 females

The length of exposure varied from 28 to 32 d. The rats were weighed before and after exposure to the magnetic field. Before the termination of the study, individual animals were placed in metabolic cages away from the magnets for 24 h in order to collect urine specimens. Twenty-four hours after the end of exposure, all animals were sacrificed following cardiac puncture for blood samples. At autopsy, all organs were weighed and sections taken for Hematocylin and Eosin, Periodic Acid Schiff, and Alcian Blue Staining.

RESULTS

In vivo study: The mesenteric capillaries examined microscopically *in vivo* were normal and showed no intravascular thrombosis, whatever the length of the exposure to the magnetic field.

Histopathological and laboratory studies:

A) *Weight*: All the rats weighed 94 ± 11 g before the start of the experiment. Rats exposed to the magnetic field gained significantly more weight than did those in the control group (Fig. 1). The weight gain was greater for males than for females. This increase in weight appeared to be related to magnetic field intensity. Final weight of brain, thymus, spleen, heart, kidney, liver, and testes was also significantly higher in the group of animals exposed to magnetic fields (Table I). Adrenals, ovaries, and lungs had the same final weight in each group. The ratio of thymus weight/body weight was significantly larger in the three groups of exposed rats than in the control group.

B) *Histopathology*: There was no alteration of the vascular bed, particularly in the muscles and in the heart, no matter what the strength of the magnetic field. There was no intravascular thrombosis and no pathology of the artery walls related to magnetic exposure. Nonspecific foci of pneumonitis were found in both control and experimental groups, indicating a nonspecific type of infection. Spleen congestion was present in the two groups: 2 rats out of 6 in the control group, 2 out of 4 exposed to 200 Gauss, 2 out of 5 exposed to 400 Gauss. All five rats exposed to 1200 Gauss had a congestion of the spleen. No alteration in the adrenal glands, the liver, the gonads, or the central nervous tissues was found.

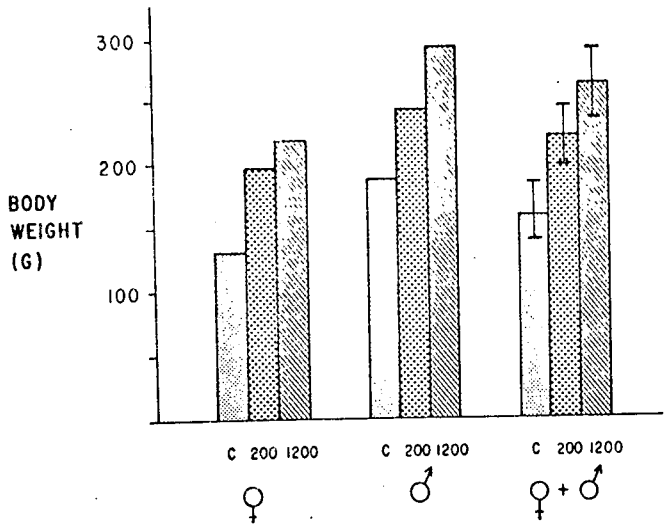

Fig. 1. Mean values of final body weight in each group of rats. All rats had approximately the same weight before the experiment: 94± 11 g. I = standard deviation.

C) *Hematology and clinical chemistry*: No unusual pathological alterations causally related to the magnetic fields were apparent: there were no significant changes in the hematocrit, the white blood cell count, and the hemoglobin level. The coagulation time was similar in all groups.

DISCUSSION

In vivo study of the small arteries of the rat omentum: The intravascular occlusion by small electric currents observed by Sawyer *et al.* (16) might have been caused by experimental conditions different from the present ones. In Sawyer's experiment, current electrodes were applied to either edge of the rat mesoappendix. Total currents of 20 μA with a pole potential difference of 20-30 mV and a transvascular potential drop of 1-3 mV resulted in intravascular occlusion of the small arteries. In the present experiments, the voltage generated across a small artery with a 300 Gauss strength magnetic field was calculated: in this vessel, with an inside cross section of 0.1 mm (2), a blood velocity of 1 g/s would generate in such a magnetic field a voltage across the blood stream

TABLE I. MEAN BODY AND ORGAN WEIGHT OF THREE GROUPS OF RATS.

Final Weight	Control (N=6)	200 Gauss (N=4)	1,200 Gauss (N=5)
Body	160 ± 43.7	220.3 ± 31*	262.0 ± 51.6*
Brain	1.50 ± .2	2.12 ± 0.09*	2.04 ± 0.11*
Lungs	1.65 ± .7	1.05 ± 0.17	1.62
Thymus	0.42 ± 0.04	0.68 ± 0.16*	0.62 ± 0.13*
Heart	0.58 ± 0.1	0.87 ± 0.15*	1.02 ± 0.08*
Spleen	0.60 ± 0.14	0.98 ± 0.10*	1.70 ± 0.8*
Adrenals	0.10	0.10	0.10
Kidneys	1.46 ± .24	1.98 ± 0.39	2.46 ± 0.56*
Ovary	0.10(3)	0.2(2)	0.1(2)
Testes	2.80(3) 0.014	3.7(2) 0.014*	4.1(3) 0.001*
Liver	8.41 ± 2.9	12.60 ± 0.75*	12.50 ± 1.86*

* Significantly different from control
( ) number of animals

of about 0.05 mV. (For a vascular tissue where such small capillaries would represent as much as 25% of the cross section of the perfused tissue, the voltage across each capillary would be only 50% larger than for the same capillary alone). This voltage is about 1000 times smaller than the one applied directly by Sawyer *et al.* to obtain an intravascular thrombosis.

Histopathological and laboratory studies:

A) *Body and organ weight gain*: Exposure to the highest field used in this study (1200 Gauss) did not produce any casualty or apparent ill effect. These findings are in agreement with those reported by others who studied effects of much higher magnetic fields on animals and man: Beischer (6) reported that survival of animals was not affected by transient exposure to 100,000 Gauss. In man, exposure of up to 15 min to a homogeneous magnetic field of 2,500-20,000 Gauss does not induce any apparent ill effect (5).

The significant increase in total body weight as compared to that of the control group was also reflected in the increase in organ weight (Table I) of the animals exposed to magnetic fields. No such increase in body weight of growing rodents has been reported in the literature. On the contrary, Barnothy (1-2) reported a decrease in body growth of 4-week-old mice exposed for 70 d to a magnetic field of 4,000 Gauss. Further documentation of the effect of magnetic fields of low intensity on growth and development is now warranted.

B) *Histopathology*: There were no positive histopathologic findings except for congestion of the spleen, particularly in the high (1,200 Gauss) exposure and the nonspecific pneumonitis present in all groups. Other authors have conducted histopathologic studies on mice exposed for up to 30 d to 4,000 Gauss magnetic fields and did not report apparent ill effects (12). Others, using much higher fields, report a relative reticulosis of the spleen (3), a centrolobular necrosis with regeneration of the liver, and a narrowing of the zona fasciculata in the adrenal glands (17). The present experiments do not show any alteration of the nervous tissue in the 15 rats exposed to magnetic fields of 200 to 1,200 Gauss strength during 28-32 d of continuous exposure. These results are in agreement with the work of Einselen (12) and of Friedman *et al.* (18) on primates exposed to 200 Gauss for 40 h.

C) *Hematology and clinical chemistry*: No difference was noted between the control group and the rats exposed to magnetic fields. The red blood cell count, the leucocyte count, and the blood coagalation time were not significantly different in both groups. Barnothy (1-2), using different experimental conditions, reported the following results: mice exposed for 35 d to a magnetic field of 4,200 Gauss present a 20 to 40% decrease in circulating leucocytes, which reach a maximum decrease between the 12th and the 16th d; the leucocyte count returns to normal between the 18th and the 21st d and decreases again the 30th d. Removal of mice from the magnetic field at the low point of the leucocyte count results in a rise of the leucocytes to 20% above the baseline level within 2 weeks. The red blood cell count increases after 1 week exposure to a magnetic field of 13,000 Gauss.

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