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ORIGINAL ARTICLE

A 1-μT extremely low-frequency electromagnetic field *vs.* sham control for mild-to-moderate hypertension: a double-blind, randomized study

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The effects of extremely low-frequency electromagnetic fields (ELF-EMFs) on blood pressure (BP) are controversial. In this double-blind, randomized, sham-controlled study, we examined the effects of repeated exposure to a 1-μT ELF-EMF on BP in 20 humans with mild-to-moderate hypertension. Subjects were randomly assigned to either the ELF-EMF group or the sham group. Subjects in the ELF-EMF group were exposed to an ELF-EMF (6- and 8 Hz, respectively, peak magnetic field 1 μT, peak electric field 10 V m^{-1}) for at least two 10- to 15-min sessions per week, over a period of 4 weeks. In the sham group, the EMF-generating apparatus was not active. We obtained systolic and diastolic BP (SBP and DBP, respectively) measurements at registration and before and after each ELF-EMF exposure session. Subjects in the ELF-EMF and sham groups had mean ages of 52.8 and 55.1 years, and were exposed to a mean of 9.9 and 9.0 sessions, respectively. There was a significant difference between the ELF-EMF and sham groups with respect to change in SBP value between baseline and the end of the exposure regimen (P=0.02), but not with respect to change in DBP (P=0.21). There were no adverse events other than mild paresthesia of the hands of two subjects in the ELF-EMF group. Our results suggest that repeated exposure to an ELF-EMF has a BP-lowering effect on humans with mild-to-moderate hypertension.
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Keywords: blood pressure; ELF; magnetic field; randomized trial

INTRODUCTION

Hypertension is an important public health concern worldwide.[1] There are an estimated 30 million hypertensive patients in Japan and an estimated 43 million in the USA.[2,3] It is well established that alleviating hypertension can reduce the incidence of cardiovascular events;[4] however, 30–46% of patients undergoing medical treatment for high blood pressure (BP) are not compliant with drug therapy for various reasons, including treatment cost and adverse effects.[5] Perhaps because of this, there has been growing interest in other treatment modalities for lowering BP, including complementary and alternative medicine approaches such as acupuncture and qigong, and new methods such as the use of electromagnetic fields (EMFs).[6–10]

In a recent review, Okano discussed various studies showing that static magnetic fields have a hypotensive effect on BP in animals (including rats, mice and rabbits).[8] In several studies, extremely low-frequency (ELF)-EMFs have been shown to have no effect on systolic BP (SBP) or diastolic BP (DBP) in humans.[11–15] However, in a self-controlled study of 60 hypertensive subjects, each of whom was exposed to ten 12- to 15-min sessions of a 50-Hz 30-mT EMF, Chiuich and Orekhova found that the ELF-EMF induced a significant decrease in BP.[16] In that study, posttreatment peripheral vascular resistance was decreased compared with pretreatment,[16] which may have acted to ameliorate hypertension.[16]

In the 1950s, Schumann hypothesized that EMF signals could resonate in the cavity between the Earth's surface and the ionosphere.[17] The Schumann resonances are simply the electromagnetic resonances of the global Earth–ionosphere (quasi) spherical-shell cavity.[18] It consists of a spectrum of ELF resonant peaks with a fundamental frequency of about 7.8 Hz and broad resonant peaks typically at 14-, 20-, 26-, 33-, 39-, 45- and 51 Hz.[19] The Schumann resonance modes happen to be within the frequency range of electroencephalogram bands (that is, alpha 8–13 Hz and beta 14–30 Hz).[19,20]

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Interestingly, Mitsutake *et al*. researched the relationship between human BP and Schumann resonance, and found that SBP and DBP were lower on enhanced Schumann resonance days than on other days.[20] Such ELF-EMF has been shown to affect BP. Studies of rats exposed to ELF-EMFs in the frequency band of 0.01–100 Hz (with magnitudes of 5, 50 and 5000 nT) have revealed that ELF-EMFs at frequencies of 0.02, 0.5–0.6, 5–6 and 8–11 Hz had the greatest impact on the circulatory system.[21] We previously conducted a self-controlled study of 30 subjects, each of whom was exposed to at least fifteen 10-min sessions of a 6- and 8-Hz 1-μT ELF-EMF, and we found that the ELF-EMF induced a significant decrease in the BP of subjects with hypertension.[22] Based on the results of these previous studies, we considered it possible that ELF-EMFs could represent an alternative approach for controlling hypertension. To test this hypothesis, we conducted the present double-blind, randomized, sham-controlled study on the effects of a 1-μT 6- and 8-Hz ELF-EMF on BP in hypertensive human subjects.

METHODS

At enrollment, for each subject, we obtained demographic information, physical measurements (height and weight) and information on medical history (history of hypertension, use of antihypertensive drugs and inclusion/exclusion criteria as listed below). We also measured BP and performed electrocardiograms and chest X-rays. At enrollment, at the end of the exposure period and 6 months after the exposure, all subjects underwent urine analysis and blood tests, including complete blood counts and blood biochemistry tests (albumin, creatinine, aspartate aminotransferase, alanine aminotransferase and lactate dehydrogenase levels).

All subjects enrolled in this study were aged between 20 and 74 years, were employees of Ichikawa Construction and had mild-to-moderate hypertension according to the World Health Organization/International Society of Hypertension criteria (SBP of 140–179 mm Hg and/or DBP of 90–109 mm Hg).[23] Interday differences in SBP and DBP were no more than 30 and 15 mm Hg, respectively. Both men and women were included in the study.

Exclusion criteria were as follows: severe essential hypertension, secondary hypertension, or malignant hypertension; history or symptoms of cerebrovascular accident; history of myocardial infarction; history or symptoms of angina pectoris, atrial fibrillation, arrhythmia, or cardiac failure; renal dysfunction (serum creatinine >2.1 mg per 100 ml); severe hepatic dysfunction; uncontrolled diabetes; allergy, drug hypersensitivity, or chronic skin disorder; peptic ulcer; pregnancy, suspected pregnancy, or breastfeeding; depression requiring treatment; hypertension controlled using an antihypertensive drug; and other causes for exclusion as determined by the principal investigator or coinvestigators. Hypertensive subjects whose condition was not successfully controlled by using an antihypertensive drug were included in this study. Subjects continued to use antihypertensive drugs during the study.

The study was done in accordance with the International Conference on Harmonisation and the Declaration of Helsinki, and subsequent revisions. The study protocol and other relevant documents were reviewed and approved by the Ethics Committee of the Kyoto University Graduate School and Faculty of Medicine, and the Ethics Committee of Ichikawa Construction. Written informed consent was obtained from all participants. The study was monitored by an independent safety monitoring board. There was no external funding source.

Electromagnetic devices

The ELF-EMF was generated by an electromagnetic device (Ichikawa Construction, Gifu, Japan) comprising a pair of square-shaped coils, each of which was mounted within a housing frame (height (H), 300 cm; length (L), 170 cm; and diameter 2.5 cm). The device was set up in a room 121.6 m^3 in size. The axis of the coil frames was placed perpendicular to the geomagnetic field. The distance between the coil frames was 300 cm. During exposure sessions, subjects sat on a chair placed between the coils. The paired coils produced a sinusoidal 6- and 8-Hz EMF with peak magnetic field of 1 μT and a peak electric field of 10 V m^{-1} at the point where subjects sat. The EMF was controlled by two functional generators (DF1905; NF, Kanagawa, Japan), and the peak values were measured using an EMF meter (ME3830B; Gigahertz Solutions GmbH, Langenzenn, Germany and MGM-1DS; Aichi Micro Intelligent, Aichi, Japan). The background value of the geomagnetic field in our laboratory was ~46 to 47 μT (data from the World Data Center for Geomagnetism, Kyoto, Japan). At the point where the subjects sat, there was low-level urban EMF noise (a few nT).

The sham exposure apparatus involved an identical apparatus installed in another room of the same size. Both the two rooms were located in the offices of Ichikawa Construction, and were very similar in all respects. In the EMF room, the exposure system was switched on between 0800 hours and 1200, so to ensure that subjects underwent treatment or sham treatment during the same time period, we used two different rooms. The only difference between the two rooms was whether or not there was an electrical cable connecting the generator and the coils, but in any case the subjects could not see this. Both rooms were kept at 22.0 ± 1.0 °C. Only one employee of the Ichikawa Construction knew which subjects were in the exposure group and which in the sham group, but he kept this information strictly confidential, was not involved in administering the study and was not a subject. None of the subjects had been involved in any way with the manufacturing or setup of this system.

Study design and procedures

We performed a randomized, double-blind, sham-controlled trial. Subjects were randomly assigned to either the ELF-EMF group or the sham group. Neither the subjects nor the medical staff overseeing the exposure session and taking BP measurements knew which group each subject was in.

Subjects in the ELF-EMF group were exposed to the 1-μT ELF-EMF for at least two 10- to 15-min sessions per week for 4 weeks. Only one session was permitted per day. The sham group was treated in the same way as the ELF-EMF group, except that the EMF-generating apparatus was not turned on. During the exposure or sham exposure period, medical personnel observed the subjects. After exposure/sham treatment, the subjects were asked questions relating to any physical and mental changes that they had experienced during the exposure. Medical doctors asked subjects about their condition at the end of the exposure period and 6 months after the exposure. Adverse events were recorded when they occurred over the course of the study. During the 6-month follow-up period, subjects were free to receive any medical treatment.

BP measurements

Registration values were recorded 1 month or less before the start of the exposure regimen, and these measurements were used to assess whether subjects were hypertensive. At each exposure session, subjects' BP and pulse rate were measured three times just before the exposure and three times just after the exposure. The mean of the three readings was used for analysis. Measurements were made by a trained nurse using an automated sphygmomanometer (TM-2655P; A&D, Tokyo, Japan) with an appropriate cuff size, with the arm at heart level and with the subject in the sitting position. All BP measurements were performed between 0800 hours and 1200 at a fixed time for each individual.

Study outcomes

The primary outcome of this study was the difference between the ELF-EMF and sham groups with respect to the absolute change in SBP value between baseline (the average of the registration and preexposure values for the first session for each subject) and the end of the exposure regimen (the average of the preexposure values for the last two sessions and the values obtained 1 week after the treatment ended for each subject). The secondary outcomes were the difference between the ELF-EMF and sham groups with respect to the absolute change in DBP value between baseline (the average of the registration and preexposure values for the first session for each subject) and the end of the exposure regimen (the average of the preexposure values for the last two sessions and the values obtained 1 week after the treatment ended), the change in both SBP and DBP values between preexposure and postexposure for each session (averaged over the regimen) and the incidence of adverse events.

Statistical analysis

Data management and statistical analysis were conducted at the Department of Clinical Trial Design and Management, Translational Research Center, Kyoto University Hospital. Based on the results of a previous self-controlled study,[22] the sample size (n=10 in each arm) was calculated to detect a 12 mm Hg reduction in SBP, assuming a s.d. of 9 mm Hg, a two-sided significance level of 0.05 and a power of 80%. Differences between the two groups with respect to the changes in SBP and DBP values between baseline and the end of the exposure regimen and each pre- and postexposure session were tested using the *t*-test. A value of 0.05 indicated statistical significance. Statistical analyses were performed using SAS ver. 9.1 (SAS Institute, Cary, NC, USA). This study is registered with the ClinicalTrials.gov (no. NCT00709930).

RESULTS

Subject characteristics

The first subjects were enrolled on 28 January 2008. All subjects had their first exposure or sham exposure session on 18 February 2008. Subject characteristics, hematologic data and blood biochemistry data at registration, at the end of the exposure regimen and 6 months after the end of the exposure regimen are summarized in Table 1. One subject was excluded from analysis because after enrollment her BP turned out not to meet the eligibility criteria (as described in the Methods section). The mean ages of subjects in the ELF-EMF and sham groups were 52.8 years (range 38–69 years) and 55.1 years (range 47–74 years), respectively. Subjects in the ELF-EMF and sham groups were exposed to a mean of 9.9 sessions (range 8–15 sessions) and 9.0 sessions (range 8–15 sessions), respectively. Four subjects in the sham group took antihypertensive drugs during the study period. The subjects were taking (1) amlodipine besylate 5 mg and telmisartan 40 mg, (2) amlodipine besylate 2.5 mg, (3) valsartan (dose unknown) and (4) amlodipine besylate (dose unknown). Two subjects in the ELF-EMF group took drugs during the study period. These subjects took (1) losartan potassium 50 mg and (2) unknown.

BP and adverse events outcomes

There were no adverse events other than mild paresthesia of the hands in two subjects in the ELF-EMF group, who described the feeling as a lack of sensation that resolved quickly and spontaneously. Thus, no statistical analysis was performed on adverse event data. Data on baseline and pre- and postexposure BP measurements are given in Table 2. There was a statistically significant difference between the ELF-EMF and sham groups with respect to the absolute change in SBP value between baseline and the end of the exposure regimen (-11.7 ± 6.0 mm Hg in the ELF-EMF group *vs.* -3.2 ± 8.3 mm Hg in the sham group, P=0.02; *t*-test; Table 2). However, there was no statistically significant difference between the ELF-EMF and sham groups with respect to the absolute change in DBP value between baseline and the end of the exposure regimen (-5.6 ± 3.7 mm Hg in the ELF-EMF group *vs.* -3.1 ± 4.5 mm Hg in the sham group, P=0.21; *t*-test; Table 2). There was no statistically significant difference between the ELF-EMF and sham groups with respect to the change in either SBP or DBP values between pre- and postexposure for each session (P=0.23 and P=0.49, respectively; *t*-test). There was, however, a statistically significant difference between the ELF-EMF and sham groups with respect to the change in SBP values between pre- and postexposure in the first week (considering all exposure sessions in the first week; P=0.02, *t*-test; Table 2 and Figure 1).

Additional analysis

As shown in Table 1, hematologic and blood biochemistry findings were almost identical in the two groups. In the ELF-EMF group, pre- and postexposure SBP values were below 140 mm Hg, except for preexposure SBP in the first week (Table 2). In contrast, in the sham group, pre-and postexposure SBP values were above 140 mm Hg, except for postexposure SBP in the fourth week (Table 2).

Two-way repeated-measures analysis of variance was used to compare the response patterns in terms of SBP values in the ELF-EMF and sham groups. There were significant differences between the ELF-EMF and sham groups with respect to SBP (including baseline values and values 1 week after the treatment ended) (P=0.04) and measurement date (baseline, first to fourth weeks, 1 week after treatments ended) (P=0.0018), but there was no significant difference between the preexposure and postexposure

Table 1 Demographic and hematological characteristics of subjects in the ELF-EMF and sham groups at registration (data are ± s.d.)

	ELF-EMF group			*Sham group*		
	Registration	*End of the exposure regimen*	*6 months after the end of the exposure regimen*	*Registration*	*End of the exposure regimen*	*6 months after the end of the exposure regimen*
Sex (male/female)	10/0			9/0		
Age (years)	52.8 ± 10.2			55.1 ± 7.9		
Height (cm)	172.2 ± 5.0			170.3 ± 6.5		
Bodyweight (kg)	78.5 ± 11.1			73.9 ± 9.1		
Albumin (g per 100 ml)	4.6 ± 0.3	4.4 ± 0.2	4.4 ± 0.3	4.8 ± 0.1	4.6 ± 0.2	4.7 ± 0.2
AST (IU l^{-1})	31.1 ± 21.1	27.3 ± 18.3	34.2 ± 39.8	32.3 ± 12.6	25.4 ± 6.1	24.1 ± 4.9
ALT (IU l^{-1})	45.2 ± 52.9	38.2 ± 48.1	39.7 ± 48.3	36.2 ± 19.9	29.8 ± 19.2	24.6 ± 14.1
LDH (IU l^{-1})	190.9 ± 23.1	181.7 ± 23.4	206.9 ± 33.7	187.4 ± 22.7	167.0 ± 24.1	179.9 ± 25.8
Creatinine (mg per 100 ml)	0.9 ± 0.1	0.8 ± 0.1	0.9 ± 0.1	1.0 ± 0.2	1.0 ± 0.2	0.96 ± 0.2
Leukocyte count (per μl)	6630 ± 2838	5990 ± 1530	6730.0 ± 2382	6688.9 ± 1465	6455.6 ± 1415	6288.9 ± 1622
Platelet count ($\times 10^4$ per μl)	25.1 ± 9.7	22.6 ± 3.2	22.4 ± 4.2	24.5 ± 3.6	23.8 ± 4.0	24.7 ± 4.4
Neutrophil (%)	58.8 ± 7.2	56.5 ± 5.2	56.1 ± 5.3	57.5 ± 6.3	58.2 ± 6.1	56.7 ± 6.7
Eosinophil (%)	2.9 ± 1.9	2.9 ± 1.4	3.1 ± 1.5	4.6 ± 2.7	5.0 ± 2.7	5.1 ± 2.9
Basophil (%)	0.9 ± 0.5	0.8 ± 0.4	0.7 ± 0.7	0.7 ± 0.3	0.6 ± 0.5	0.2 ± 0.4
Lymphocyte (%)	31.9 ± 6.3	33.0 ± 5.1	35.0 ± 4.4	30.8 ± 4.6	29.9 ± 7.2	33.0 ± 6.3
Monocyte (%)	5.5 ± 1.0	6.8 ± 1.5	5.1 ± 1.0	6.4 ± 1.9	6.3 ± 1.6	5.0 ± 1.3

Abbreviations: ALT, alanine aminotransferase; AST, aspartate aminotransferase; ELF-EMF, extremely low-frequency electromagnetic field; LDH, lactate dehydrogenase.

Table 2 Mean baseline and pre- and postexposure SBP and DBP (mm Hg) values for the ELF-EMF and sham groups (data are shown as mean ± s.d.)

	Baseline	*1st week*	*Post—pre (1st week)*	*2nd week*	*Post—pre (2nd week)*	*3rd week*	*Post—pre (3rd week)*	*4th week*	*Post—pre (4th week)*	*Post-pre (Overall, 1st-4th weeks)*	*1 week after the treatment ended*	*End of the exposure regimen*
ELF-EMF group												
Pre-SBP	145.8 ± 11.7[a]	142.1 ± 12.1		139.2 ± 10.8		137.4 ± 11.0		133.1 ± 9.0			135.2 ± 13.6	134.1 ± 8.7[a]
Post-SBP		135.0 ± 9.8	−7.1 ± 6.0	132.4 ± 11.1	−6.8 ± 8.6	134.8 ± 11.8	−2.6 ± 10.6	131.6 ± 9.5	−1.5 ± 8.4	−4.5 ± 8.8[b]		
Pre-DBP	93.1 ± 9.1[c]	91.3 ± 9.2		90.5 ± 8.0		88.8 ± 8.8		86.0 ± 8.7			86.0 ± 8.1	87.5 ± 7.4[c]
Post-DBP		88.8 ± 8.1	−2.5 ± 2.7	88.8 ± 8.0	−1.6 ± 4.0	89.1 ± 8.3	0.2 ± 6.1	85.5 ± 8.0	−0.4 ± 5.1	−1.1 ± 4.7[b]		
Pre-PR		75.8 ± 12.0		75.3 ± 13.1		76.8 ± 11.6		73.4 ± 14.3				
Post-PR		74.3 ± 11.7	−1.6 ± 2.4	73.7 ± 11.3	−1.5 ± 3.4	76.3 ± 10.9	−0.5 ± 3.2	72.2 ± 13.4	−1.2 ± 3.3			
Sham group												
Pre-SBP	146.1 ± 13.5[a]	149.6 ± 13.1		146.7 ± 10.1		142.6 ± 14.2		143.4 ± 12.7			143.8 ± 20.8	142.9 ± 14.0[a]
Post-SBP		146.9 ± 12.3	−2.7 ± 5.2	143.0 ± 11.0	−3.7 ± 8.7	141.1 ± 11.6	−1.4 ± 8.1	139.1 ± 9.8	−4.3 ± 6.2	−3.0 ± 7.2[b]		
Pre-DBP	97.9 ± 8.9[c]	100.5 ± 10.0		100.0 ± 7.9		96.0 ± 11.3		95.6 ± 9.0			94.6 ± 11.7	94.8 ± 9.2[c]
Post-DBP		99.5 ± 10.5	−1.0 ± 4.6	98.5 ± 9.4	−1.5 ± 6.7	95.0 ± 8.6	−1.0 ± 6.5	92.6 ± 9.1	−3.0 ± 4.4	−1.6 ± 5.6[b]		
Pre-PR		73.9 ± 7.8		74.2 ± 8.1		73.9 ± 7.2		75.9 ± 9.2				
Post-PR		72.0 ± 6.3	−1.9 ± 2.9	72.6 ± 7.4	−1.6 ± 2.7	72.5 ± 7.0	−1.4 ± 2.2	73.6 ± 7.5	−2.2 ± 3.8			

Abbreviations: DBP, diastolic blood pressure; ELF-EMF, extremely low-frequency electromagnetic field; Post, postexposure; PR, pulse rate; Pre, preexposure; SBP, systolic blood pressure.
Data for each week are averages for all sessions in that week. Post—pre indicates the postexposure value minus the preexposure value.
[a]Primary outcome: there was a statistically significant difference between the ELF-EMF and sham groups with respect to the absolute change in SBP value between baseline and the end of the exposure regimen (−11.7 ± 6.0 mm Hg in the ELF-EMF group *vs.* −3.2 ± 8.3 mm Hg in the sham group, P=0.02; *t*-test).
[b]Secondary outcome: there was no statistically significant difference between the ELF-EMF and sham groups with respect to the change in either SBP or DBP values between pre- and postexposure for each session (P=0.23 and P=0.49, respectively; *t*-test).
[c]Secondary outcome: there was no statistically significant difference between the ELF-EMF and sham groups with respect to the absolute change in DBP value between baseline and the end of the exposure regimen (−5.6 ± 3.7 mm Hg in the ELF-EMF group *vs.* −3.1 ± 4.5 mm Hg in the sham group, P=0.21; *t*-test).

Figure 1 Differences between the ELF-EMF and sham groups with respect to mean absolute changes between preexposure and postexposure SBP.

values (P=0.35). The interaction between group (ELF-EMF group *vs.* sham group) and measurement date was statistically significant (P=0.0003).

DISCUSSION

Given that the effects of ELF-EMFs on BP are controversial, we conducted a carefully designed, randomized, controlled study to examine the effects of a 1-μT ELF-EMF on BP in human subjects. In our study, there was a significant difference between the ELF-EMF and sham groups with respect to absolute change in SBP value between baseline and the end of the exposure regimen (P=0.02; *t*-test). However, there were no significant differences between the ELF-EMF and sham groups with respect to absolute change in DBP value between baseline and the end of the exposure regimen (P=0.21; *t*-test), nor with respect to change in SBP and DBP values pre- and postexposure session (P=0.23 and P=0.49; *t*-test). Two-way repeated-measures analysis of variance was used to compare the response patterns in terms of SBP values in the ELF-EMF and sham groups. The interaction between group (ELF-EMF group *vs.* sham group) and measurement date was statistically significant (P=0.0003), indicating that the response patterns differed significantly between the ELF-EMF and sham groups.

A potential limitation of this study was the small sample size. However, we calculated an appropriate sample size based on data obtained in a previous study,[22] and the power of this study approximately corresponded with the planned value (see statistical analysis); hence we conclude that the small sample size is not a major problem. To calculate the actual power of this study, we took the difference in SBP value between the two groups (see Table 2: −11.7+3.2=−8.5 mm Hg) as delta and arrived at a value of 0.60 (s.d.=8.2 in the control and ELF-EMF groups). We enrolled subjects who were taking antihypertensive drugs, but whose BP had not normalized. These subjects kept taking their antihypertensive drugs during the study. Although the differing antihypertensive medications and doses being taken by subjects represent a potential confounding factor, four subjects in the sham group and two in the EMF group were taking antihypertensive drugs (that is, fewer in the EMF group). Therefore, we think that the factor is not likely to have affected our conclusion that EMF has some effect on BP. Another limitation of our study was that smoking and alcohol consumption were not controlled, both of which have an effect on BP. Both smoking and alcohol consumption were permitted during the study period, but subjects were asked to refrain from smoking before treatment.

No serious adverse events were reported by subjects during the ELF-EMF exposure regimen period or during the follow-up period. Of all hematological factors, only the change in monocyte count over the exposure regimen (value at the end of the exposure regimen minus value at registration) differed significantly between the ELF-EMF and sham groups (P=0.04, t-test). At present, the significance of the increase in monocyte count following ELF-EMF exposure is unknown.

The results of the present study correspond to some extent with those of a study by Chiuich and Orekhova.[16] In that study, hypertensive subjects were treated with 10 sessions of a 50-Hz 30-mT ELF-EMF for 12–15 min, applied to either the forehead or neck, resulting in a significant lowering in SBP.[16] The differences between the results of Chiuich and Orekhova and those of studies in which it was found that ELF-EMFs had no effect on BP[11–15] may have been caused by differences in the EMF frequency, magnetic flux density, number of exposure sessions, exposure sites (whole body, head or neck) or subject characteristics. In Chiuich and Orekhova's study, the subjects were exposed to 10 sessions of ELF-EMF,[16] whereas in other studies, subjects were exposed to only 1 or 2 sessions.[11–13,15] In addition, in Chiuich and Orekhova's study, subjects were hypertensive, whereas the subjects were normotensive in other studies.[11–15] In our study, subjects with clinically well-defined hypertension were involved; thus, the status of the subjects seems to be important in eliciting an effect of ELF-EMFs on BP. This argument may be supported by our observation that ELF-EMF exposure seemed to have a greater effect on subjects in the ELF-EMF group at the start of the study (for example, during the first week, there were significant differences between the ELF-EMF and sham groups with respect to change in SBP values pre- and postexposure session), but had a lesser effect as subjects became normotensive (Table 2 and Figure 1). This may indicate that ELF-EMF acts to normalize BP. Static magnetic fields have been found to have a normalizing effect on BP; that is, an antihypertensive effect on hypertensive animals and an antihypotensive effect on hypotensive animals.[8] Therefore it is possible that ELF-EMF does not decrease BP beyond a normotensive level. In fact, in this study, there was a statistically significant difference between the ELF-EMF and sham groups with respect to the change in SBP values between pre- and postexposure in the first week (considering all exposure sessions in the first week; P=0.02, t-test; Table 2 and Figure 1). In the second week, this tendency was also evident, but not in the third and fourth weeks when SBP values in the ELF-EMF group reached normotensive levels (Figure 1).

The exposure level used by Chiuich and Orekhova was 30 mT, 30 000 times stronger than the 1 μT field used in our study. Moreover, these authors used a 50 Hz field, as opposed to the 6–8 Hz used in the present study. Therefore, the underlying mechanism of the effects observed may differ from those observed in our study, but frequency may explain why moderate-intensity (mT range) static magnetic fields or ELF-EMFs and weak-intensity (μT range) ELF-EMFs may have the same effect on BP. Animals seem to be most sensitive to ELF-EMFs below 10 Hz . For example, studies of rats exposed to ELF-EMFs have revealed that frequencies of 0.02, 0.5–0.6, 5–6 and 8–11 Hz had the greatest impact on the circulatory system (as described in the Introduction).[21] One hypothesis explaining the results of these previous studies is that humans may be especially physiologically sensitive to ELF-EMFs below 10 Hz, even when low magnetic flux densities are used. If true, this may be beneficial for the future clinical use of ELF-EMFs because the weak field used in our study (6- and 8 Hz, 1 μT, 10 V m^{-1}) meets the guidelines of the International Commission on Non-Ionizing Radiation Protection.[24]

The potent effects of static magnetic fields on BP have been linked to the nitric oxide pathway, the Ca^{2+}-dependent pathway, the sympathetic nervous system (for example, baroreflex sensitivity and the actions of sympathetic agonists or antagonists) and the neurohumoral regulatory system (for example, production and secretion of angiotensin II and aldosterone), as reviewed by McKay *et al.*[25] The precise mechanism by which ELF-EMFs might ameliorate hypertension is unknown; however, there are two hypotheses that may explain the effect. One potential hypothesis is that the effect of EMFs may be mediated by melatonin release. There is good evidence showing that EMF affects melatonin release,[26] and Reiter *et al.* suggest that the night time rise in endogenous circulating melatonin levels may be inversely related to the reduction in night time BP.[27] In this study, we asked each subject to undergo their BP measurements at the same time of day (as far as possible) over the entire duration of the study period. Therefore, the effect of circadian rhythm on BP would be minimal. The other hypothesis involves an effect of ELF-EMF on blood vessel diameter. Trakov *et al.* investigated changes in blood vessel diameter during and after application of three different frequencies (10-, 16- and 50 Hz) of ELF-EMF for 10 min.[28] In the 16-Hz exposure group, significant vasodilatation was observed in the postexposure period compared with the preexposure and exposure periods, but no significant effects were shown for the 10- and 50-Hz exposure groups.[28] This result suggests that there may be a 'window effect' at 16 Hz for mean blood vessel diameter.[28] One of the authors of the present study, K. Mohri, is a magnetic sensor specialist and inventor of a magnetoimpedance sensor. The magnetoimpedance sensor can detect 50 pT magnetic fields without shield room.[29] In a pilot study, using an magnetoimpedance sensor, we found that exposure of humans to our ELF-EMF for 10 min altered their blood flow. Subjects were a 68-year-old male and female who were exposed to 10 min ELF-EMF.[30] The magnetoimpedance sensor head was set to measure at the right side of cervical spine.[30] Using this apparatus, they clearly detected the increased magnetic signal resulting from blood flow after ELF-EMF exposure.[30] Thus, blood vessel resistance is decreased and blood flow may be increased.

There was a statistically significant difference between the ELF-EMF and sham groups with respect to the absolute change in SBP value between baseline and the end of the exposure regimen. Our findings suggest that repeated ELF-EMF exposure has an effect on SBP. This finding warrants a larger controlled clinical trial to determine whether long-term repeated exposure to 1-μT ELF-EMFs has a beneficial effect on hypertensive humans, such that it could reduce dependence on or obviate the need for pharmacotherapy.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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