Clinical Biochemistry 46 (2013) 59–63

Contents lists available at SciVerse ScienceDirect

Clinical Biochemistry

journal homepage: www.elsevier.com/locate/clinbiochem

Long-term (up to 20 years) effects of 50-Hz magnetic field exposure on immune system and hematological parameters in healthy men ☆

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ARTICLE INFO

Article history:
Received 14 June 2012
Received in revised form 7 September 2012
Accepted 10 September 2012
Available online 17 September 2012

Keywords:
Magnetic fields
Hematology
Immunology
Immunoglobulins
Lymphocyte subsets
Cytokines

ABSTRACT

Objectives: The relationship between exposure to 50-Hz magnetic fields and human health is of increasing interest since associations have been found in brain cancer in adults and childhood leukemia. In this study we investigate the possible chronic (up to 20 years) effects of exposure to magnetic fields in humans.

Design and methods: We examined the nocturnal profiles of red blood cells, hemoglobin, hematocrit, platelets, mean platelet volume, total white blood cells, lymphocytes, monocytes, eosinophils, basophils, neutrophils, Ig (Immunoglobulin) A, IgM, IgG, CD (cluster of differentiation) 3, CD4, CD8, natural killer cells, B cells, total CD28, CD8+ CD28+, activated T cells, interleukin (IL)-2, IL-6, and IL-2 receptor, in 15 men exposed chronically and daily for a period of 1–20 years, in the workplace and at home, to a 50-Hz magnetic field. The weekly geometric mean of individual exposures ranged from 0.1 to 2.6 μT. The results are compared to those of 15 unexposed men age-matched, with the same synchronization and physical activity that served as controls (individual exposures ranged from 0.004 to 0.092 μT). Blood samples were taken hourly from 20:00 h to 08:00 h.

Results: Exposure over a long period and on a daily basis to magnetic fields resulted in no changes in the levels or patterns of hematological and immune system variables.

Conclusions: Our data show that a long-term exposure to 50-Hz magnetic fields does not affect the hematological and immune system functions or their profile in healthy men, at least for the variables studied, and suggest that magnetic fields have no cumulative effects on these functions.

Introduction

Any electric installation can create in its vicinity an electric field, a magnetic field or a combination of both (electromagnetic field) which is propagated in space in the form of non-ionizing electromagnetic waves. These fields are characterized by their frequency (expressed in hertz or Hz) or their wavelength (in meter or m). The environmental exposure to the electromagnetic fields generated by the human activity has increased regularly, in parallel with the electric demand for electric power. We all are thus exposed to a complex compound of electric and magnetic fields of low intensity. The levels of exposure of the general population are 5 to 50 V/m for the electric fields and 0.01 to 0.2 μT for the magnetic fields. These fields are primarily those related to the use of the electrical current (50 Hz in Europe, 60 Hz in the United States). The question of the possible health risk by exposure to the electric and/or magnetic fields became a concern of the scientists and an important public debate.

A number of investigations, carried out in particular by the World Health Organization (WHO), concluded on the basis of thorough examination of the scientific publications from many countries that the existing data do not allow the establishing of the existence of medical effects [1] however; our knowledge of the biological effects of the electromagnetic fields still involves certain holes that will have to be filled. The very low frequencies, ELF (Extremely Low Frequency), are present around lines of electric transport, transformers, alternators, electric hardware, and equipment of arc- and resistance-soldering.

In spite of the many studies carried out for 20 years, one is still far from being able to conclude with certainty on their harmfulness or their harmlessness. Only in certain harmful effects, such as the effects of the electrical currents induced in the human body by low frequencies, that the human reactions related to contact currents are scientifically acknowledged. Indeed, the many epidemiologic studies concerning the emergence of cancer per exposure to electromagnetic fields are conflicting. Presently, certain work connecting the risk of leukemia in the child with the event of exposure to electromagnetic fields of

☆ This work has been granted by Electricité de France (EDF) and Réseau de Transport d'Electricité (RTE). The entire protocol was performed at the Clinical Investigation Center (CIC) of Pitié-Salpêtrière Hospital in Paris and was approved by the hospital ethics committee.
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http://dx.doi.org/10.1016/j.clinbiochem.2012.09.003

extremely low frequency [2,3] generated in their dwelling indicates that this risk can exist when the children are subjected chronically to an exposure greater than 0.4 μT (the relative risk is about 2).

The majority of the research dedicated to the effects of electromagnetic fields on immune system and hematology dealt with short duration exposures, on average of 30 min to 24–48 h whereas only few studies focused on long-term effects in humans [4,5], because of the inherent difficulties in this type of protocol. The goal of the present study is to investigate in workers chronically exposed to electromagnetic fields both at work and at home whether such a chronic exposure (between 1 and 20 years duration) affects the immuno-hematological parameters.

Materials and methods

Subjects and experimental protocol

Thirty middle-aged men volunteered to participate in the study. Selection criteria included that they were non smokers and drank coffee and/or alcohol moderately, had no acute or chronic diseases, had no sleeping disturbances, were not night or shift workers, did not take any drug and had not traveled across several time zones during the preceding two months. They were all synchronized with daytime activity from 07:00 h to 23:00 h and nocturnal rest and kept similar schedules and physical activities. According to their working profile they were assigned to the sub-group of exposed ($N = 15$, mean age $= 38.0 \pm 0.9$ years, range 31.5 to 46) or control subjects ($N = 15$, mean age $= 39.4 \pm 1.2$ years, range 34.5 to 47). The subjects were instructed not to use electric devices such as razors or hair dryers 24 h before or during the study. Those who were exposed at work had not been on duty in 48 h before the experiment started.

The control subjects ($N = 15$) were recruited by the Centre d'Investigation Clinique (CIC) of Pitié-Salpêtrière Hospital and among the white-collar workers at EDF. None had a professional position that could have resulted in occupational exposure to magnetic fields. They were subjected only to the normal electromagnetic fields of our daily environment. All the subjects underwent routine clinical and laboratory examinations to assess general health, endocrine profile, and current blood counts.

The entire protocol was performed in autumn (light:dark cycle, LD 10:14) at the CIC of Pitié-Salpêtrière Hospital in Paris and was approved by the hospital ethics committee. All volunteer subjects were asked to provide a written informed consent. The protocol was done in accordance with the ethical principles and standards for the conduct of human research in chronobiology [6]. Exposure at the CIC was low, similar to normal residential levels, i.e. around 0.05 μT.

The subjects arrived at the CIC between 18:00 h and 18:30 h. The catheter (15 cm long, to avoid awakening subjects for the nocturnal blood samples) was inserted in an antecubital vein at 19:00 h. The study extended over a 12-h period: it started at 20:00 h and lasted till 08:00 h the next morning. The subjects were free until 22:00 h, except that they were not allowed to watch television or to play video games in order to avoid whatever magnetic field exposure that might bias the study. Lights were turned off from 22:00 h to 08:00 h. Since the CIC could house only 2 volunteers a night, the study was staggered over 5 weeks for the exposed and over 7 weeks for the control subjects.

Blood samples (EDTA (ethylenediaminetetraacetic acid) tubes) were taken hourly from 20:00 h to 08:00 h the next morning ($N = 13$). To standardize the posture-related sampling conditions, all the subjects remained seated for 15 min preceding the samples taken at 20:00 h and 21:00 h and were recumbent for the remaining samples.

Magnetic field exposure and their measurements

The exposed volunteers ($N = 15$) worked in extra high voltage (EHV) substations in the Paris metropolitan region, operating and maintaining the EHV electricity transmission network (225 kV and 400 kV). Their main tasks included installing couplings between EHV lines and voltage transformers. The density of electric lines was responsible for the high magnetic field levels in substations. Moreover, the exposed subjects dwelled near the substations and were thus exposed to magnetic fields while at home. Ten of the 15 subjects had been exposed from 7 to 20 years and 5 subjects from 1 to 4 years.

The magnetic field exposure for one week was recorded for each subject with EMDEX II dosimeters (Enertech Consultants, Campbell, California, USA); its measuring range is from 10 nT to 300 mT (accuracy $\pm$ 10%) for frequencies between 40 Hz and 800 Hz. The device is autonomous and measures B magnetic induction in space in all 3 directions, then computes the resulting value of B (quadratic sum of each of the three vectors) and stores it in the device's memory.

Magnetic field measures for exposed and control subjects were recorded for 7 days, during the daytime and at night. Measurements were taken and recorded every 30 s. Both exposed and control subjects wore the recording device throughout the workday, and at home, they placed it in a "public" room. Dosimeters were also worn at the CIC.

Data for both groups were transferred to a computer system after 7 days of dosimetry and the statistical calculations were performed with the EMCALC software (Enertech, California, USA) provided with the dosimeters. The following parameters were calculated for the total exposure (7 days) and for total daytime and nighttime exposure: lowest value, highest value, weekly arithmetic and geometric means with their standard deviations, and median.

Immune system and hematological variable measurements

Mononuclear cells were isolated from venous blood. T-cell subsets were evaluated by an indirect immunofluorescence technique using CD (cluster of differentiation) 3, CD4 and CD8 antibodies (Serotec, Oxford, UK). CD3 antibodies recognize human T-cells, CD4 recognize helper T-cells and CD8 recognize suppressor T-cells. At least 200 cells per sample were counted using a fluorescence microscope. Lymphocyte immunophenotyping was performed by the two-color flow cytometric method, using matched combinations of murine monoclonal antibodies directly conjugated to fluorescein isothiocyanate (FITC) or phycoerythrin (PE). A lysed whole-blood technique and paraformaldehyde fixation were used. The levels of activated T and NK cells expressing CD69 were measured on a flow cytometer using a three color immunofluorescence staining protocol. All samples were analyzed by using a FACScan flow cytometer (Becton Dickinson Immunocytometry Systems, Sparks, MD, USA) [7]. The coefficient of variation (CV) for this technique was 6%. Cytokine measurements were performed using a competitive enzyme immunoassay (EIA) (R&D Systems, Minneapolis, MN, USA). All assays were performed blind.

Hemoglobin, hematocrit, platelets, red blood cells, total white blood cells (leukocytes) and total lymphocytes were measured by using an automated blood cell analyzer (Coulter STKS, Coulter electronics, Luton, UK). Respective CVs were 1.0, 1.5, <4.5, 1.5, <3.0, and 15.0%.

Statistical analysis

Repeated-measures analysis of variance (ANOVA) was used to check the statistical significance of the differences between the controls and the exposed subjects. The raw values obtained before any transformation were used for ANOVA. The differences were considered to be statistically significant when P (probability) was less than 0.05. For each variable studied, the statistical analysis examined the following three factors: the hour factor, the field effect factor and the hour $\times$ field interaction. The F (F-ratio) and P values are shown in Tables 1, 2, and 3. The repeated-measures factor corresponds to the circadian variation of the variables studied. Our hypothesis was that a magnetic field might affect the profile of these variables. For this reason, we were especially