THE IMPACT OF EMF ON THE CARDIOVASCULAR FUNCTION: BASIC METHODOLOGICAL PROBLEMS AND STUDY RESULTS

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INTRODUCTION

The electromagnetic fields are commonly present both in the communal and work environments. The potential hazard they may pose to human health is a matter of dispute among scientists. The external electric and magnetic fields have a theoretical potential to affect the functions of different body systems through generating electric impulses within them. Most sensitive to EMF influence are the cardiovascular and nervous systems, particularly the autonomic nervous system responsible, among others, for neurovegetative regulation of the cardiovascular function. The experimental studies conducted thus far indicate that EMF within radio-, microwave and power frequencies can produce measurable biological effects. However, there is no simple relation between the biological and health effects. The biological effects detected at the cell or tissue level may not, and most often do not, translate into overt health effects, owing to the adaptation and repair mechanisms of the living organisms. Moreover, the findings of experimental animal studies can hardly be extrapolated to humans in view of the anatomic and functional differences between species.

Therefore, for evaluating health effects of EMF exposure, the most significant are experimental, clinical or epidemiological studies on humans. The experimental studies make it possible to assess immediate response but not the delayed effects. Consequently, they are of little use for the assessment of effects of occupational exposure that may last several years. Much more valuable are the clinical studies. However, these have been rather scarce so far. Although there are quite a few reports on such studies conducted in the former Soviet Union, they have been commonly criticized for several methodological drawbacks and deficiencies, including ad hoc selection of the study population, lack of control group, lack of accurate assessment of electromagnetic environment, and lack of adjustment for the confounding factors [1]. Further, the methods applied may not have been relevant to the study objectives. To assess the cardiovascular function, the authors most frequently used resting ECG and office BP measurements which are inadequate for detecting functional impairments or early subclinical signs of cardiac dysfunction.

Epidemiological studies can provide the best evidence on the possible health effects of EMF exposure. The studies performed thus far were intended mostly for the assessment of cancer risk from EMF exposure. The results of the first epidemiological study concerning the cardiovascular system were published in 1999. Savitz et al. [2] examined the mortality from cardiovascular diseases in relation to occupational exposure to 50 Hz EMF in a cohort of 138 903 male electric utility workers from five US companies over the period of 1950-88. Age-, race-, and social class-adjusted long-lasting exposure to high level EMF was associated with an increased risk of death from arrhythmia-related conditions: (n=212) SMR=1.11-2.04 and acute myocardial infarction: (n=4238) SMR=1.07-1.66. These data suggest a possible association between occupational EMF exposure and arrhythmia-related heart disease.

Few epidemiological studies on non-carcinogenic effects of radio frequency and microwave EMF exposures have been published. It was only the questionnaire studies on subjective complaints among mobile phone users and physiotherapists [3-5].

Since 1993, in Nofer Institute of Occupational Medicine, has been conducting comprehensive studies on the neurovegetative regulation of the cardiovascular function in workers exposed to different frequency EMFs [6-9]. The aim of these studies is to investigate the influence of EMF exposure on the cardiac function and find out whether and to what extent the EMF frequency and exposure level can determine the type of cardiovascular abnormalities and neurovegetative function affected.

METHODS

For the study, the non-invasive methods of 24-h ECG (Holter) and blood pressure (ABP) monitoring have been applied which are useful for the examinations of healthy individuals during their normal professional and daily activities. These methods are helpful in detecting not only the clinical manifestations of the disease, but also in early diagnostics of a dysfunction of the cardiovascular system. The examinations were carried out in compliance with the standards of the International Society for Holter and Noninvasive Electrocardiology [10]. The protocol was approved by the Regional Biomedical Ethics Committee.

In all workers the following examination were performed:

- *anamnesis*, with an interview on the risk factors of cardiovascular diseases: family history of metabolic and cardiovascular diseases, lifestyle, nutritional habits and physical activity,

- *routine physical examination*, with office blood pressure measurement (according to WHO guidelines),
- *routine ECG* during rest in the supine position, using Medea system (Gliwice, Poland) from 12 typical leads. The results obtained were evaluated based on generally adopted standards,
- *24 h ECG monitoring* on normal workday, using Medilog Suprima (Oxford, England) set from three bipolar leads. This method is thought to ensure the most accurate diagnostics of cardiac rhythm disturbances, conduction impairments and ischemia, especially silent ischemia. Final results, including heart rate, symptoms of ischemia, arrhythmia and conduction disturbances were related to the international standards for Holter ECG [10],
- *Blood pressure monitoring (ABP)* 24-h ambulatory blood pressure monitoring (ABP) was performed during everyday professional and other activities using DX-Medilog Systems. The measurements were carried out automatically, every half hour during daily activities and every hour during sleep. Mean, systolic (BPS) and diastolic (BPD) blood pressure and heart rate (HR) for 24 hours (O), day-time activity (D) and night-time rest (N) were calculated and related to the Staessen's standards of arterial blood pressure as the reference values [11]. The day-night ratios were determined for systolic and diastolic blood pressure (BPSD/BPSN, BPDD/BPDN). Subjects with BP ratio lower than 1.1 are called the 'non-deepers' (subjects without a physiological nocturnal decrease in systolic and/or diastolic blood pressure).

To assess the worker's individual exposure to EMF, the following parameters were measured:

- in workers at substations: maximum value of electric field strength (E_{max}), maximum value of magnetic flux density (B_{max}) and doses per workshift - E_{Dose} and B_{Dose},
- in workers at AM broadcasting stations and radioservices: maximum value of electric field strength ($E_{max)}$ and dose per workshift - E_{Dose},
- in workers at broadcasting stations: maximum value electric field strength (E_{max}), mean value of E (E_{mean}) and lifetime dose of E (E_{dose}) separately for VHF, UHF and VHF+UHF. Our assessment of exposure was based on the spectrum analysis of a typical station broadcasting in UHF and VHF bands and on the specifications of the apparatus installed there.

For electric and electromagnetic fields measurement, the HOLADAY Ind. (USA) measuring set and MEH-1a meter (Technical University, Wroclaw, Poland) were applied. Lifetime dose was calculated for each worker from the history of employment and job timetable.

SUBJECTS

The groups under study consisted of technical personnel and security service workers who were qualified by the occupational health practitioners as capable for work at permissible EMF levels. The subjects were randomly selected from the total number of such stations in Poland. All workers at each appointed station were examined. All subjects from the exposed and control groups gave their formal consent prior to inclusion in the study. Before the onset of the examinations, all the procedures were explained in detail to each participant.

The examinations were carried out in:

- AM broadcasting stations - exposed group I. The AM stations selected for the study operate at frequencies ranging from 738 kHz to 1503 kHz. These objects can be characterized by permanent exposure of their workers to electromagnetic fields (mostly electric). The main source of EM fields in the AM stations are the transmitting antennas (half-wave dipole), radio transmitters and feeders (which conduct radio signals from the transmitter to the antenna),
- Radioservices - exposed group II. Mobile radio-communication network requires permanent technical supervision by radioservice units. During the service operations, undesirable EM fields are generated by unscreened transmitters, improper tuning instruments and transmitting-receiving antennas installed in the service-rooms. The radioservice workers under study were exposed to EM fields with frequency varying from 150 to 170 MHz,
- Substations - exposed group III. Substations are the element of a power system, in which electric power is distributed and/or transformed. The substations under study work at high and extra high voltage (110 kV- 400 kV). The substation equipment is a source of 50 Hz electric and magnetic field,
- Broadcasting stations that operate at frequencies ranging from 66 MHz to 727 MHz - exposed group IV,
- Radio Link Stations - the control group (0). Radio Link Stations are the elements of a telecommunication system in which signals are transmitted using EM waves focused into very row beams by directional (mostly parabolic) antennas. As the antennas are installed in highly inaccessible locations and the radiation beams run high above the ground, the workers of the Radio Link Stations are free from being exposed.

The exposed groups were similar with respect to the level of physical fitness, and dietary and smoking habits. They differed only with regard to the age. The possible influence of this difference on the study results was eliminated using statistical methods.

Table 1. Characteristics of the study population

	Exposed groups				Control group
	AM Broadcasting Stations (I)	Radioservices (II)	Substations (III)	Broadcasting stations (IV)	Radio Link Stations (0)
Number of subjects	71	40	63	71	42
Age (years)	46.9±13.1*	36.9±11.5	39.0±10.0	45.3±9.4	40.7±2.2
Employment (years)	18.6±12.1	12.5±9.5	15.0±10.0	19.1±8.8	17±13
Diseases diagnosed:					
hypertension	12 (17%)	6 (15%)	11 (17%)	11 (15%)	8 (19%)
diabetes, type II	1	0	0	1	1
Subjective symptoms	31 (44%)	26 (65%)	30 (46%)	36 (51%)	15 (29%)
Body mass index (BMI)	26.0±3.0	25.0±3.0	26.0±4.0	26.9±3.8	25.4±4.0
No. of smokers (more than 10 cigarettes a day)	33 (47%)*	15 (37.5%)	21 (33%)	17 (24%)	17 (40%)

BMI (body mass index) = body mass/height^2 (kg/m^2)

* statistically significant difference ($p \leq 0.05$)

RESULTS

Table 2. EMF exposure in the study groups

Groups	Exposed				Non-exposed
	AM Broadcast Stations (I)	Radio-services (II)	Substations (III)	Broadcasting stations (IV)	Radio Link Stations (0)
EMF frequency	738-1503 kHz	150-170 MHz	50 Hz	66-727 MHz	0
E_{max}	50-550 [V/m]	2-55 [V/m]	4.3-6.7 [kV/m]	7.9-16.7 [V/m]	0
B_{max}	negligible	negligible	26.1-37.3 [mT]	negligible	0
E_{dose}	50-260 [(V/m)h]	irregular exposure	0.2-15.2 [(kV/m)h]	50-260 [(V/m)h]	0
B_{dose}	negligible	negligible	1.4-38.9 [mTh]	negligible	0

In all the exposed groups, the assessment of EMF exposure revealed levels not higher than those attributed to the hazard area (exposure indicators lower than 1).

Table 3. Percentage of subjects with ECG and blood pressure abnormalities

Groups	A: resting ECG	B: Holter monitoring	A and/or B	ABP	Office BP
AM broadcasting stations (I)	34	56	83	6	20
Radioservices (II)	30	32.5	55	20	22.5
Substations (III)	29	40	48	38	19
Broadcasting stations (IV)	34	44	59	70	34
Radio Link Stations (0)	26	31	40	23	19
p	ns	I vs. 0 (p=0.02)	I vs. 0 (p=0.001)	III vs. 0, IV vs. 0 (p=0.04)	ns

In the exposed groups an increased frequency of cardiovascular abnormalities and impaired neurovegetative regulation of the cardiac function was found (table 3).

The risk analysis revealed that the probability (odds ratio) of abnormalities in resting and/or 24h ECG was 6.6 for group I, 2.0 for group II, 1.4 for group III and 4.5 for group IV, as compared with the control group. On the other hand, the ABP monitoring revealed that when compared to the values found for controls, the risk of elevated blood pressure was lower in group I, comparable in group II, and significantly higher in group III. The increased BP values referred mainly to systolic pressure at night (odds ratio=12.5). In group IV, the risk of elevated arterial blood pressure was 8.6. The disturbances in ECG and blood pressure regulation were dependent on EMF exposure level. In group I, a significant relationship was found between mean BPSN and E_{dose} (p.=0.004) as well as between BPSN and E_{max} (p = 0.03). In group II, the relationship between BP level and exposure parameters was not analysed. Such an analysis could not be performed due to the specific job characteristics in this group - the workers were periodically exposed to

EMF emitted by the repaired equipment and it was impossible to determine the level of their exposure. In group III, BP disturbances significantly correlated with exposure parameters. BPDO, BPDD, and BPDN were found to depend on the period of employment (p=0.023, p=0,05, p=0.001 respectively). A significant correlation was found between BPSN and BPDN and the maximum values of electric and magnetic fields (p=0.043 and p=0.026). In group IV, the disturbances in blood pressure regulation were dependent on EMF exposure parameters. The risk of BP changes increased with higher lifetime dose in the UHF-VHF bands (OR=2.3) as well as higher E_{mean} in the UHF and VHF bands (OR=2.3, OR=2.5, respectively). The risk of impaired BP regulation (no nocturnal blood pressure drop) significantly increased with lifetime dose in the UHF range (OR=2.6) and with a growing E_{mean} in the VHF range (OR=2.1).

DISCUSSION AND CONCLUSIONS

Although the occupational exposure limits, as laid down in respective Polish regulations, were not exceeded, the different impairments in circulatory system were observed in exposed workers. In workers at AM broadcasting stations, heart rhythm disturbances, detected by 24-h ECG monitoring, were more frequent than in the non-exposed workers as well as workers exposed to 50 Hz EMF. On the other hand, in workers at substations and broadcasting stations, an increased frequency of elevated BP (detected with ABP) was found, compared with other groups. Our results suggest that the frequency of EMF determines the type of the observed cardiovascular disturbances. Significant BP disturbances occurred mainly at night; therefore, the office BP measurement is inadequate to detect them. It is also worth noting that in EMF-exposed workers, increased BP levels in ABP could be found both in the persons showing normal and increased BP values in a single office measurement. Therefore, the present scope of prophylactic examinations seems to be inadequate for workers occupationally exposed to EMF and it should be extended with 24h monitoring of the ECG and blood pressure.

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