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TIME-DEPENDENT HEMATOLOGICAL CHANGES IN WORKERS EXPOSED TO ELECTROMAGNETIC FIELDS

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A World War II-era study, involving the effects of electromagnetic fields (EMFs) emanating from radars and high-frequency radios on the blood of exposed workers, was analyzed for evidence of the effect of time in the manifestation of changes in the hematological system. Statistically significant correlations between increasing white blood cell count and average daily exposure, months of exposure, and total duration of exposure to EMFs were found. Changes in cell count were within the normal range, and thus their relation to epidemiological studies linking EMFs and leukemia, if any, is unclear. Results suggest that the time of exposure may be an additional factor (along with field strength, and perhaps frequency) in ascertaining the safety of EMF exposure.

The role of time in the elaboration of biological effects in human subjects due to exposure to electromagnetic fields (EMFs) is controversial. Acute effects arising from neural stimulation and tissue heating have long been recognized,[1] and the goal of obviating health risks mediated by these mechanisms was the rationale for the original standard for safe exposure levels of EMFs promulgated by the American National Standards Institute (ANSI).[2] In this view risk is associated with EMF strength and perhaps frequency, but is independent of time of exposure. Over the years the adopted threshold has decreased,[3] but time has consistently been excluded as a factor mediating risk; the ANSI standard is voluntary, but is widely followed in industry and government.[4]

In apparent contrast with the rationale for the voluntary standard, the EMF epidemiological studies are unanimous in imputing risk, if it exists at all, to situations involving long-term exposure. When job classifications were used as a surrogate for EMF exposure, more than the expected number of cases of leukemia were found.[5-7] Among males who died from acute myeloid leukemia, an increased relative risk was found for the occupations that involved exposure to EMFs;[8] similar results were found in other studies.[9] Amateur radio operators died more often than expected from leukemia.[10] In all these studies the subjects were exposed to EMFs for prolonged periods.

There are several mechanisms by which the presence of an EMF over time could result in increased incidence of disease. The probability of oncogenesis could be increased in the presence of an EMF compared with its absence, in which case the role of time in manifesting increased disease levels would be a result of the cumulative probability of a rare event. Laboratory studies provide a possible molecular basis for the occurrence of EMF-induced events that might subserve oncogenesis.[11] Alternatively, cumulative EMF exposure could burden one or more of the body's regulatory systems, leading to a progressive escape from regulation. Since cancer of the blood-forming elements is frequently reported in connection with EMF exposure, it is reasonable to expect that any progressive change would be manifested in a phenotypic change in blood cells. The report of an association between EMF exposure and polycythemia might be an example of progressive disregulation of blood-forming elements.[12] Another possibility is neuroendocrine-mediated immunosuppression, and evidence suggesting a role of the central nervous system has been presented.[13]

The applicability of a threshold-based standard that excludes possible time-based mechanisms can be evaluated by examining subjects exposed to similar EMFs for varying lengths of time: a correlation between time of exposure and a change in magnitude of a biological parameter would be evidence of the importance of time. Pertinent data was provided in a report published at the dawn of consideration of the EMF health-risk issue,[14] and the results of an analysis of the effect of time on the measured parameters are provided here.

METHODS

During World War II, at the request of the Bureau of Ships, investigators at the Naval Research Laboratory (NRL) studied the health status of civilian personnel and the emission characteristics of the experimental radar and high-frequency radio equipment with which they worked. The purpose of the project was to determine whether the equipment gave off harmful radiation and, if so, to identify the harm produced. The expressed

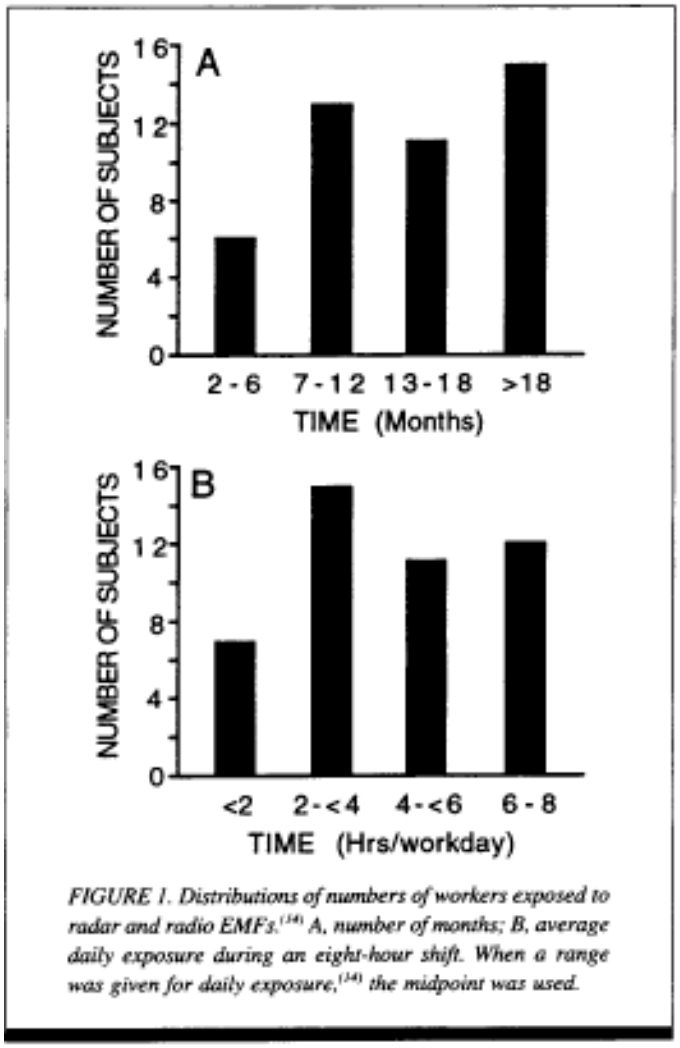

FIGURE 1. Distributions of numbers of workers exposed to radar and radio EMFs.[14] A, number of months; B, average daily exposure during an eight-hour shift. When a range was given for daily exposure,[14] the midpoint was used.

concern was for ionizing radiation, and the possibility that exposure to nonionizing radiation could also be harmful was not explicitly mentioned. The final report of the project (which was not published) described the radiation emitted by the equipment and the results of clinical measurements and physical examinations of exposed personnel; the results of the clinical study were published,[14] and that report, which provided the only available demographic and clinical data, is the basis of this analysis.

A total of 45 male subjects was studied; the means by which they were selected was not described, but it appears to have included the entire cohort of civilian personnel working with experimental radar and radio at the NRL. The duration of exposure of individual workers varied from a minimum of two months to a maximum of nine years. Periodic blood counts and physical examinations were performed during a one-year observation period, and the following data were presented for each subject: number of months of EMF exposure at NRL; average exposure during an eight-hour shift (in hours); red blood cell (RBC) count; white blood cell (WBC) count; hemoglobin; and WBC differential count. A general description of observations from physical examinations also was given. The reported data and observations related to the last examination of each subject within the observation period. It seems reasonable to expect that the exposure experienced by the subjects encompassed a variety of radar systems and job activities, but no data were presented regarding either factor; individual data were given, however, regarding the number of hours per day of exposure and number of months on the job.

The hemoglobin data were expressed only in relative units, and the differential involved too few cells for analysis. Sufficient data were provided, however, to calculate the linear correlation coefficients between blood cell counts and the logarithm of the time of exposure.

RESULTS

The average daily exposure of the workers to EMFs varied from 1 to 8 hours per 8-hour shift, and the months of exposure varied from 2 to 52 months for 44 subjects, and was 108 months for 1 subject; the distributions are shown in Figure 1.

There were no serious illnesses among the exposed personnel, but patient histories revealed the occurrence of frontal headaches in 22% (10/45) of the subjects. The headaches were not severe and usually occurred after several hours of exposure and disappeared about an hour after cessation of exposure. Three subjects reported a sensation of mild heat in the face or hands when they were directly exposed to the EMF. One of the concerns that prompted the study was the possibility that EMFs might cause alopecia, but no such cases were observed.

The WBC count from six subjects was over 10 000/μL, and the clinical observations in these cases were that the subjects were suffering from an upper respiratory infection at the time the count was taken, and one other subject was infected with an intestinal parasite; the data from these seven subjects was not considered here. The RBC count was not correlated with time of exposure to EMFs (Table I). In contrast, WBC count was significantly correlated with months of exposure, average time of exposure during the workday, and with total exposure, which is a measure of the cumulative number of hours of EMF exposure; WBC count scattergrams are shown in Figure 2.

DISCUSSION

The white cell count increased progressively with number of months of exposure to EMFs (Figure 2A) and with average daily exposure (Figure 2B). When a time measure involving the total number of hours of EMF exposure was computed by multiplying the number of months of exposure x the average daily exposure for each subject, the resulting values also were correlated with

TABLE I. Correlation Coefficients Between Time and Blood Cell Count in EMF-Exposed Workers[A]

	Correlation Coefficient	
Time	*White Cells*	*Red Cells*
Months	0.36 (0.02)	0.14 (NS)
Hrs/workday	0.63 (0.0001)	0.10 (NS)
Total exposure	0.56 (0.0002)	0.14 (NS)

[A]Total exposure is months x hrs/workday. Corresponding P values are given in parentheses. NS, not significant.

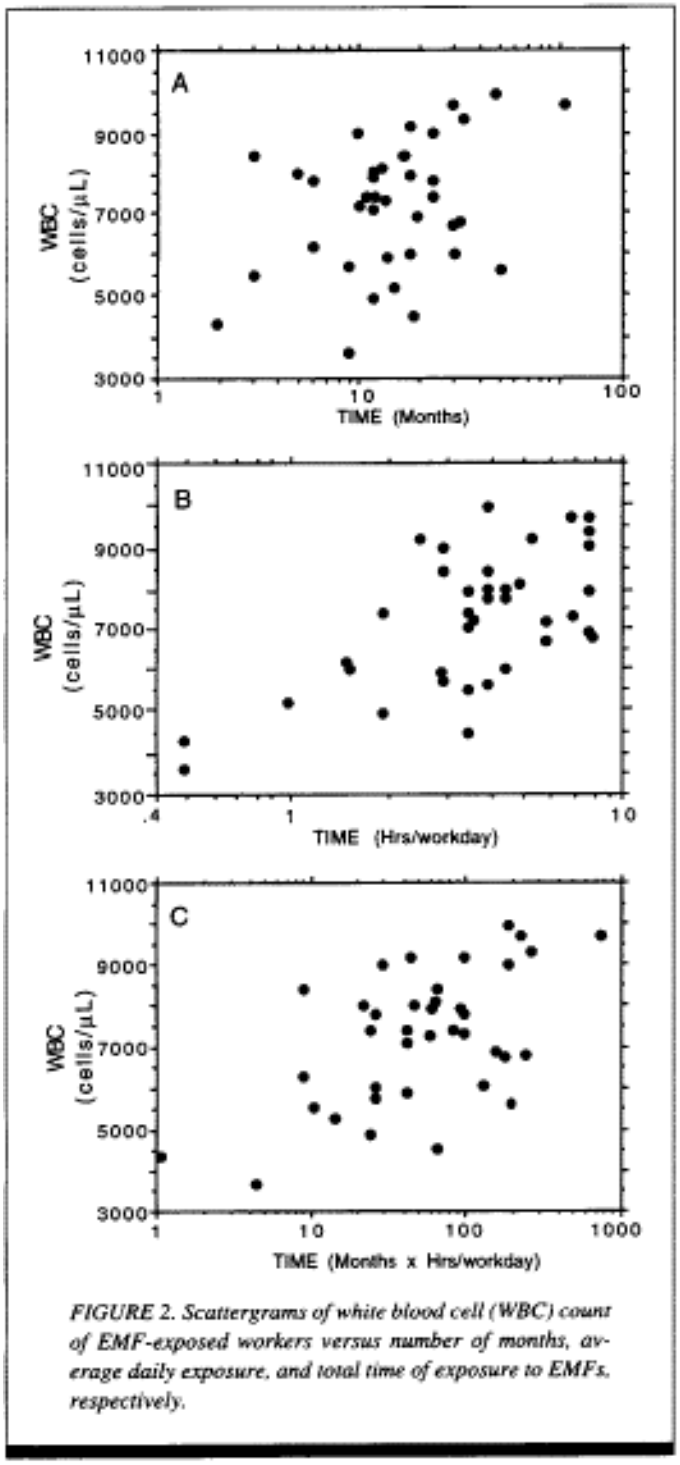

FIGURE 2. Scattergrams of white blood cell (WBC) count of EMF-exposed workers versus number of months, average daily exposure, and total time of exposure to EMFs, respectively.

WBC count (Figure 2C). Only three subjects reported subjective sensations of heat, and consequently heating seems an unlikely reason for the observed correlation. The original study[14] provided no evidence that the radar and radio equipment were sources of ionizing radiation, and a contemporaneous study reported that the nonionizing radiation produced by the equipment consisted of soft x-rays that could not penetrate the steel and aluminum cabinets of the equipment.[15] Although a role for nonionization radiation (or other possible confounding factors) cannot be completely discounted, the data suggests that the amount of time of exposure to nonionizing EMFs proportionately affected white cell count, with higher counts being manifested in subjects who had a greater cumulative exposure.

The study was performed in the early days of the modern era of epidemiology, and it lacked data concerning demographics, job descriptions, smoking status, selection criteria, and EMF characterization; but these same limitations also are found in present-day EMF epidemiological studies.[5-10] Although the limitations must be considered, they seem unlikely to have produced a false positive association between WBC count and exposure time, because nothing in the study suggests that they occurred differentially or pursuant to a pattern. The likely effect of the various potential confounders, therefore, would be to obscure an association between EMF exposure and WBC count because the confounders would amount to randomizing influences.

Other studies have involved occupational or residential exposure to radar, but they do not bear directly on the results reported here. Servicemen (124 subjects) exposed for various periods had a mean WBC count similar to that of unexposed controls (20 subjects); however, reticulocyte concentration was significantly greater in the exposed group.[15] In a larger study (40 000 subjects) naval personnel exposed to radar were split into two groups based on job titles (high and low (relative) EMF exposure), and the mortality rates in the two groups were found to be identical.[16] However, both groups were exposed to EMFs; moreover, despite an overall healthy worker effect, the study subjects exhibited significantly elevated relative risks for some tissue-specific malignancies.[17] Links between residential exposure to radar and cancer also have been suggested.[18,19]

The possible relation between job-related EMF exposure and blood-cell count could be studied in subjects with occupational exposure to EMFs such as those who work with radar, communications equipment, and radio-frequency heaters. A study of blood-cell phenotype in relation to job-related exposure and incidence of cancer would permit assessment of the apparent progressive elevation of white cell count, and whether it is an indicator of a precancerous state; if so, WBC count might help to identify subjects at risk for leukemia associated with EMF exposure.

In summary, the data suggests that EMF exposure was correlated with increased WBC count, and this possibility merits further consideration, because the present de facto EMF standard[3] does not take time of exposure into consideration in arriving at a determination of a safe exposure level.

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