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Radio frequency radiation-related cancer: assessing causation in the occupational/military setting

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ABSTRACT

Background and aim: We reexamine whether radio frequency radiation (RFR) in the occupational and military settings is a human carcinogen.
Methods: We extended an analysis of an already-reported case series of patients with cancer previously exposed to whole-body prolonged RFR, mainly from communication equipment and radar. We focused on hematolymphatic (HL) cancers. We used analysis by percentage frequency (PF) of a cancer type, which is the proportion of a specific cancer type relative to the total number of cancer cases. We also examined and analyzed the published data on three other cohort studies from similar military settings from different countries.
Results: The PF of HL cancers in the case series was very high, at 40% with only 23% expected for the series age and gender profile, confidence interval CI95%: 26–56%, $p < 0.01$, 19 out of 47 patients had HL cancers. We also found high PF for multiple primaries. As for the three other cohort studies: In the Polish military sector, the PF of HL cancers was 36% in the exposed population as compared to 12% in the unexposed population, $p < 0.001$. In a small group of employees exposed to RFR in Israeli defense industry, the PF of HL cancers was 60% versus 17% expected for the group age and gender profile, $p < 0.05$. In Belgian radar battalions the HL PF was 8.3% versus 1.4% in the control battalions as shown in a causes of deaths study and HL cancer mortality rate ratio was 7.2 and statistically significant. Similar findings were reported on radio amateurs and Korean war technicians. Elevated risk ratios were previously reported in most of the above studies.
Conclusions: The consistent association of RFR and highly elevated HL cancer risk in the four groups spread over three countries, operating different RFR equipment types and analyzed by different research protocols, suggests a cause-effect relationship between RFR and HL cancers in military/occupational settings. While complete measurements of RFR exposures were not available and rough exposure assessments from patients interviews and from partial exposure data were used instead, we have demonstrated increased HL cancers in occupational groups with relatively high RFR exposures. Our findings, combined with other studies, indicate that exposures incurred in the military settings evaluated here significantly increased the risk of HL cancers. Accordingly, the RFR military exposures in these occupations should be substantially reduced and further efforts should be undertaken to monitor and measure those exposures and to follow cohorts exposed to RFR for cancers and other health effects. Overall, the epidemiological studies on excess risk for HL and other cancers together with brain tumors in cellphone users and experimental studies on RFR and carcinogenicity make a coherent case for a cause-effect relationship and classifying RFR exposure as a human carcinogen (IARC group 1).

1. Introduction and background

1.1. The scope

This paper examines whether exposure to radio frequency radiation (RFR) is a human carcinogen. We focus on occupational/military settings.

1.2. Types of exposure

Radio frequencies comprise the band of 30 kHz to 300 GHz. This includes microwaves covering the 1–100 GHz band. The major uses of RFR in the military are radio communications, radar for surveillance and weapon guidance, and electronic warfare transmitted to disrupt communications and radar. Exposures to the whole body or major parts of the body of operators and bystanders occur from a normal operation

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or from lapses in safety control at near or intermediate distances at varying intensities and wavelengths. Interaction with other exposures (e.g., ionizing radiation or toxins) is possible.

The exposure levels are usually regulated within the International Commission on Non-Ionizing Radiation Protection (ICNIRP) occupational limits (ICNIRP, 1998) and exceed them occasionally due to organizational and technical shortcomings and human errors. The ICNIRP limits are designed mainly to prevent thermal damage and permit extreme peak power of pulses, provided the average power does not exceed the thermal-based limits. The high peak power may have additional biological consequences. Assessment of exposure requires considerable resources and is difficult in many cases as reported in (Paljanos et al, 2015).

1.3. Past findings and IARC classification

Most studies in humans have focused on brain cancers from cell phone use because hundreds of millions of people experience these exposures. The possible carcinogenicity of RFR was studied extensively by epidemiology of humans — for example in (Hardell et al., 2013; Carlberg et al., 2017; Coureau et al., 2013), by animal studies with carcinogenicity possibly indicated in Chou et al. (1992); and Wyde et al. (2016); physical mechanisms such as influence on the radical oxide species in Barnes et al., 2015; and Friedman et al. (2007); and physical principles (e.g. Vistnes et al., 2001, and Peleg, 2012). In 2011, the International Agency for Research on Cancer (IARC) classified RFR as a possible human carcinogen (IARC group 2B), see IARC (2013). Hardell and Carlberg, 2013, and Carlberg and Hardell, 2017, suggested reclassifying RFR as a human carcinogen (IARC group 1) based on elevated risk ratios of mobile phone users and discussed in depth Bradford Hill's nine viewpoints from 1965 (Hill, 1965), the classical framework for causal inference in epidemiologic studies. Some reports did not detect RFR's carcinogenicity (e.g., Frei et al., 2011), which is an open and important question; see the discussion in IARC (2013).

Studies on cancers in the occupational/military setting from whole-body exposures are much fewer because the number of individuals exposed is far fewer than population-wide exposure to cellphones.

1.4. Context of this paper

In this paper, we extend our analysis of data previously reported in a case series of 47 self-referred patients with cancer by Stein et al. (2011). The patients were previously exposed to radiation from radio and radar in the occupational and military settings characterized in the “Types of exposure” section above.

We previously reported (Stein et al., 2011) that latent periods for cancer of the testes were very short, that latencies for HL cancers were longer, and that latent periods for solid cancers were even longer, suggesting a coherent and biologically plausible pattern of latency in relation to the onset of exposure to electromagnetic fields and other agents. Our approach (Stein et al., 2011) included a case versus case analysis in which the group of patients provides its own reference data. The case-case approach has been used by other researchers to rule out or remove biases possibly present in case-control studies. For example, Hardell et al. (2013), used meningioma cases as controls for other cancer cases to rule out bias from the analysis, particularly bias related to reporting the exposure by the patients. The case-case methodology has the advantage of relative freedom from many types of bias, including patient-reporting bias.

In the current paper, we perform a quantitative statistical analysis of the same case series of patients with cancer (Stein et al., 2011), focusing on characteristics of the cancers in the exposed patients group rather than on the usually reported risk ratios (RR) relative to the general population. We mainly analyze the percentage (relative) frequency (PF) of hemolymphatic cancers following the approach of Boyle and Parkin (1991) (Eq. 11. 27); see the "Materials and Methods" section for details. We will show that such an analysis is rigorous (i.e., that by using this method we can compute the probabilities of the observed cancer characteristics to occur at random by chance under the hypothesis of no causation by the exposure [p-values]). We test consistency with similar HL cancer characteristics in three other groups of patients in the military/occupational setting in three different countries using the above analysis of PF augmented by the usual RR.

2. Materials and methods

2.1. Case presentation

In the case series Stein et al. (2011), patients were referred and came to the unit of occupational and environmental medicine for the evaluation of cause-effect relationship between their cancer and their military/occupational exposure to RFR emitted by communications equipment and radar and to Extremely Low Frequency (ELF) electromagnetic fields, mainly powerlines. Most of the cancer diagnoses were during the years 1987–2007. All patients were included in the analysis and no further selection was performed. See Stein et al. (2011) for the details of patient recruitment methods. The exposure to RFR was assessed from patient's interviews and from all documentation which was available. The authors consulted with experts and the intensity range and type of exposure of each patient was estimated by an engineer based on transmitters powers and distances from antennas as available per case, see the individual exposure assessment in Stein et al. (2011).

2.2. Characterization of the patient's group

The patients were previously exposed to radiation from radio and radar in the occupational and military settings as presented in the “Types of exposure” section above. The exposures often involved the whole or many parts of the body, and not just the head. In certain cases, exposure came from equipment with direct contact – on the user's back or lap, such as in the case of radio transmitters with antenna. These exposures were often intense and irregular, varying in duration and target organs.

The patients came from the military, during or after the service, and from the electronics industry. They were in general younger than the average Israeli cancer patients as can be seen from the range of ages at diagnosis which was 18.5–64 years and from the much lower average age at diagnosis which is presented in Table 1. The individual ages at diagnosis are tabulated and analyzed in Stein et al. (2011).

The age profile of the population the patients came from is mostly the characteristic military one; more quantitative information is not available. Thus the analysis as presented below is based on ages at diagnosis which are known for all the patients.

Some patients were exposed also to ELF. Twenty three patients were exposed to RFR only, twenty one to both RFR and ELF and three to ELF only. This issue of mixed exposures is addressed in the 'Results' section below.

Some of the patients were presumably exposed to various chemicals, such as fuels and solvents, as typical in the military service and in the industry. Since the patients came from many different military units and workplaces, such an exposure is similar to that of all servicemen and workers. We expect the population of servicemen and workers to be

Table 1
Average ages at diagnosis.

Average ages at diagnosis, years		
	Patient's group in Stein et al. (2011)	Israeli general population
All cancers	33.3	65.4
HL cancers	28.9	61.9