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Letter to the Editor

When theory and observation collide: Can non-ionizing radiation cause cancer?☆

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A B S T R A C T

This paper attempts to resolve the debate about whether non-ionizing radiation (NIR) can cause cancer –a debate that has been ongoing for decades. The rationale, put forward mostly by physicists and accepted by many health agencies, is that, "*since NIR does not have enough energy to dislodge electrons, it is unable to cause cancer.*" This argument is based on a flawed assumption and uses the model of ionizing radiation (IR) to explain NIR, which is inappropriate. Evidence of free-radical damage has been repeatedly documented among humans, animals, plants and microorganisms for both extremely low frequency (ELF) electromagnetic fields (EMF) and for radio frequency (RF) radiation, neither of which is ionizing. While IR directly damages DNA, NIR interferes with the oxidative repair mechanisms resulting in oxidative stress, damage to cellular components including DNA, and damage to cellular processes leading to cancer. Furthermore, free-radical damage explains the increased cancer risks associated with mobile phone use, occupational exposure to NIR (ELF EMF and RFR), and residential exposure to power lines and RF transmitters including mobile phones, cell phone base stations, broadcast antennas, and radar installations.

1. Introduction

Whether power frequency electromagnetic fields (EMF), radiofrequency (RF) and microwave (MW) radiation can cause cancer, or other health effects, has been debated since the 1960s.[1] Scientists, who study electromagnetic energy, find themselves aligned with one of two groups and these two groups are becoming increasingly polarized.

One group adheres to the concept that, the only harmful effects associated with RF and MW radiation are due to heating, and that below thermal guidelines, this energy is safe (see quotes below). They state that the scientific evidence documenting adverse health effects is inconsistent and inconclusive and, while certain types of cancers can't be ignored, for example, childhood leukemia with residential magnetic field exposure (Ahlbom et al., 2001), the risks are small and may be due to confounders. This group relies on the well-established theory that non-ionizing radiation (NIR) does not have enough energy to dislodge electrons and therefore is unable to cause cancer.

Key authorities have made the following statements regarding health effects of NIR:

ICNIRP 2016—*The overall evaluation of all the research on HF* [*high frequency*] *fields leads to the conclusion that HF exposure below the thermal threshold is unlikely to be associated with adverse health effects.* [Note: ICNIRP (1998) recommends NIR guidelines to the WHO.]

National Cancer Institute, U.S. 2016—*Radiofrequency energy, unlike ionizing radiation, does not cause DNA damage that can lead to cancer. Its only consistently observed biological effect in humans is tissue heating.*

WHO, 2014—*A large number of studies have been performed over the last two decades to assess whether mobile phones pose a potential health risk. To date, no adverse health effects have been established as being caused by mobile phone*[2] *use.*

Health Protection Agency, U.K. 2012—*In summary, although a substantial amount of research has been conducted in this area* [*i.e. radiofrequency radiation*], *there is no convincing evidence that RF field exposure below guideline levels causes health effects in adults or children.*

Health Canada, 2010—*Based on scientific evidence, Health Canada has determined that low-level exposure to radiofrequency* (*RF*) *energy from Wi-Fi equipment is not dangerous to the public. This conclusion is consistent with the findings of other international bodies and regulators.*

☆ This paper has been recommended for acceptance by David Carpenter.

[1] NOTE: In this document ELF refers to frequencies below 300 Hz and RF refers to frequencies up to 300 GHz. MW are radio frequencies between 300 MHz and 300 GHz.

[2] NOTE: WHO makes the same statement about cell phone base stations, DECT phones, and Wi-Fi.

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FCC, 2010—*There is no scientific evidence to date that proves that wireless phone usage can lead to cancer or a variety of other health effects, including headaches, dizziness or memory loss.*

New Zealand Ministry for the Environment, 2008—*The Ministry of Health considers there are no established adverse effects from exposures to radiofrequency fields which comply with the ICNIRP guidelines and the New Zealand Standard.*

Swedish Radiation Protection Authority, 2002— *there is no biologically plausible mechanism to support a carcinogenic effect of non-ionizing RF waves.*

Clearly leading authorities state that RFR is safe below thermal guidelines and the public has nothing to be concerned about.

The other group believes that NIR is harmful at levels well below thermal guidelines, levels that are now ubiquitous in urban centers. They believe that NIR causes cancer, reproductive problems, and a range of symptoms that have been classified as electrohypersensitivity (EHS) or idiopathic environmental intolerance according to the WHO; that children and pregnant women are particularly vulnerable; and that many of the chronic illnesses common in our society are due, in part, to electromagnetic pollution or electrosmog[3] exposure. They base this belief on the numerous studies documenting adverse biological and health effects of low-level NIR (Lee et al., 1996; Havas, 2000, 2013; Carpenter and Sage, 2007, 2012; Levitt and Lai, 2010; Blank et al., 2015).

Which group is right and how do we move beyond this impasse?

2. Discussion

Let's start with the statement that: *Non-ionizing radiation doesn't have enough energy to dislodge electrons and thus cannot cause cancer.*

This assertion consists of two parts. The first part (*non-ionizing radiation doesn't have enough energy to dislodge electrons*) is based on photon energy and electromagnetic forces. The second part (*and thus cannot cause cancer*) is a conclusion based on the assumption that radiation can cause cancer *only* by dislodging electrons and breaking chemical bonds. This assumption is flawed.

Models of chemicals and ionizing radiation (IR) are repeatedly and inappropriately used to interpret the effects of NIR. With IR, photon energy is the critical criterion. With chemical toxicants, speciation and the dose are critical. With NIR we have evidence of effects within narrow intensity and frequency windows and evidence that waveform and modulation are biologically important (Blackman et al., 1989; Litovitz et al., 1990; Wei et al., 1990; Adey, 1993; Liboff, 1997; Markov, 2005). Neither chemical nor ionization models can adequately explains these observations.

In an attempt to answer the question, *Can non-ionizing radiation cause cancer,* let's begin with what appears to be a scientific anomaly.

2.1. Free-radicals, oxidative stress and DNA damage

Studies show that exposure to RFR increases free radicals in the body—leading to oxidative stress—which can account for many of the biological responses and adverse health effects, including cancer, that are documented in the scientific literature.

Since NIR doesn't have enough energy to dislodge electrons and thus create free radicals how can it contribute to an increase in free radicals?

Free radicals can “build up” in the body in one of two ways. One way is to increase free radical formation, which is what happens with ionizing radiation and certain chemicals. The other way is to interfere with the production of anti-oxidants that neutralizes free radicals. The body produces free radicals during metabolic activity and it also produces anti-oxidants as part of its natural repair mechanism. If the anti-oxidant repair mechanism is impaired free radical damage can result. The Fenton reaction that depends on free iron may play a key role in this process (Phillips et al., 2009).

Yakymenko et al. (2015) reviewed the scientific literature in a paper entitled, *Oxidative mechanisms of biological activity of low-intensity radiofrequency radiation.* In this review they provide evidence for the following:

1. RF activation of key pathways generating reactive oxygen species (ROS),
2. Activation of peroxidation,
3. Oxidative damage of DNA, and
4. Changes in the activity of antioxidant enzymes.

Ninety-three of the 100 available peer-reviewed studies, dealing with oxidative effects with low-intensity RF exposure, confirmed that RF induces oxidative stress in biological systems. The research includes studies with humans, plants and animals. Yakymenko et al. conclude that low intensity RFR is an oxidative agent for living cells and is one of the primary mechanisms accounting for the biological activity of this kind of radiation. They also claim that EHS-like conditions can be attributed, at least partially, to ROS overproduction in cells due to RFR exposures (Yakymenko et al, 2015).

Lai (2014a) tabulated abstracts of articles related to RF and free radicals. He found that 93 of 106 papers, (i.e. 88% of the studies) documented significant effects. Clearly, many publications in this field report oxidative stress associated with low-intensity RF exposure.

ELF EMF (less than 300 Hz) has even less energy than RFR and yet these frequencies have also been associated with free radical production and oxidative stress. Lai (2014b) tabulated scientific abstracts dealing with the effects of ELF EMF on free radicals. Studies include both *in vivo* and *in vitro* experiments with either acute or chronic exposure of humans, animals, plants and microorganisms. Lai (2014b) found that 97 of 110 studies (i.e. 84% of the publications) reported effects. These effects include production of free radicals and reactive oxygen species (ROS); evidence of oxidative damage including DNA and neurological damage; apoptosis; altered antioxidant enzyme activity (both increase and decrease); and altered immune system response. Forty-five of the combined RFR and ELF EMF studies (Lai, 2014a, 2014b) reported changes within the brain. Supplementation with anti-oxidant (Zn, Se, Vitamin C, and melatonin) appeared to ameliorate the harmful effects of NIR exposure.

Critics of non-thermal mechanisms are likely to argue that the evidence cited by Yakymenko et al. (2015) and Lai (2014a,b) is biased; that the studies were flawed; that specific findings are not replicable; and that most studies did not control adequately for thermal effects. So I contacted the authors to enquire how they did their searches.

Lai (personal communication) obtained his references using PubMed that he monitored almost daily for the following search terms: radiofrequency, cell phone, mobile phone, ELF magnetic field, electric field; and occasionally for specific frequencies (800 MHz, 900 MHz, 2450 MHz, etc.). His research findings included all types of responses to NIR. The 2014a,b compilation of abstracts are limited to references dealing only with free radicals and either RF or ELF EMF exposure.

Yakymenko (personal communication) stated that they analyzed all peer-reviewed experimental publications that they could find concerned with possible oxidative effects of low

[3] Note: *Electrosmog* is applied to anthropogenic sources of ELF, RF, and MW radiation and can be considered a form of non-chemical air pollution.

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