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Draft

ICNIRP Guidelines

GUIDELINES FOR LIMITING EXPOSURE TO TIME-VARYING ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS

(100 kHz TO 300 GHz)

Appendix B: Health Risk Assessment Literature

International Commission on Non-Ionizing Radiation Protection

1. INTRODUCTION

The World Health Organization (WHO) has recently undertaken an in-depth review of the literature on radiofrequency electromagnetic fields (EMF) and health, which will be released as a Technical Document in the near future. This independent review is the most up-to-date, comprehensive and thorough appraisal of the effects of radiofrequency EMFs. Further, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), a European Commission initiative, also recently produced a report on potential health effects of exposure to electromagnetic fields (SCENIHR, 2015). Accordingly, the present guidelines have used the literature review from the WHO (World Health Organization, 2014) and SCENIHR report as the scientific health literature bases for determining hazards and/or risks associated with radiofrequency EMF, rather than providing a review of the individual studies in the literature. To complement the WHO and SCENIHR reviews, ICNIRP also considered research published subsequent to that included in the WHO and SCENIHR reviews in the development of the current guidelines. In order to provide an indication of ICNIRP's evaluation process, overviews of the literature and conclusions that ICNIRP reached, as well as a limited number of examples, are provided.

The summary of the research on biological and health effects of radiofrequency EMF presented below considers effects on body systems, processes or specific diseases. This research feeds into the determination of thresholds for adverse human health effects. Research domains considered range from experimental tests of the effect of radiofrequency EMF on cells, animals and humans, to observational studies assessing relationships between radiofrequency EMF and a range of potentially health-related outcomes. The former has the advantages of being able to control a large number of potential confounders and to manipulate radiofrequency EMF exposure. However, it can also be limited in terms of generalizability to realistic exposure environments, as well as exposure durations sufficient to assess many disease processes, and in the case of in vitro and animal research, generalization to humans can also be difficult. Epidemiological research is mostly observational and thus, depending on the type of studies, various types of bias are of concern. These include confounding, selection bias, information bias, reverse causality and exposure misclassification; in general, prospective cohort studies are least affected by bias but large sample sizes are needed for rare diseases. Therefore, it is important to consider research across a range of study types in order to arrive at useful

conclusions concerning the relation between radiofrequency EMF exposure and adverse health effects.

It is important to note that ICNIRP bases its guidelines on substantiated[1] adverse health effects. This makes the difference between a biological and an adverse health effect an important distinction, where only adverse health effects require limits for the protection of humans. Research on the health effects of radiofrequency EMF has tended to concentrate on a few areas of particular interest and concern, whereas information on a number of other systems of the body is inadequate to contribute to the guidelines. Specifically, there is insufficient information about the effects of radiofrequency EMF on the skeletal, muscular, respiratory, digestive, and excretory systems. Therefore, these systems are not considered further.

2. BRAIN PHYSIOLOGY AND FUNCTION

2.1 Brain electrical activity and cognitive performance

Human research addressing higher cognitive function has primarily been conducted within the ICNIRP (1998) basic restriction values, with very limited research at levels high-enough to provide health-effect threshold information. This has primarily been assessed via performance measures, and derivations of the electroencephalogram (EEG) and cerebral blood flow (CBF) measures (sensitive measures of brain electrical activity and blood flow/metabolism, respectively). Most double-blind human experimental studies on cognitive performance, CBF or event-related potential (a derivative of the EEG) measures of cognitive function did not report an association with radiofrequency EMF. A number of sporadic findings have been reported, but these do not show a consistent or meaningful pattern. This may be a result of the large number of (uncontrolled-for) statistical comparisons, a possibility consistent with the lack of replication of such reports. Of particular importance is that the larger, more methodologically rigorous studies have failed to identify effects of radiofrequency EMF exposure on these cognitive domains. There are therefore no substantiated reports of radiofrequency EMF negatively affecting performance, CBF or event-related potential measures of cognitive function. Studies analyzing frequency components of the EEG have reliably shown that the 8–13 Hz alpha band in waking EEG and the 10–14 Hz ‘sleep spindle’ frequency range in sleep EEG, are affected by radiofrequency EMF exposure with SARs <2 W kg^{-1}, but there is no evidence that these relate to adverse health effects.

Both rodents and non-human primates have shown a decrease in food-reinforced memory performance with exposures to radiofrequency EMF at a whole body average SAR >5 W kg^{-1} for rats, and a whole body average SAR >4 W kg^{-1} for non-human primates, exposures which correspond to increases in body core temperatures of approximately 1 °C. However, there is no indication that these changes were due to reduced cognitive ability, rather than the normal temperature-induced reduction of motivation (hunger). Such changes in motivation are considered normal and reversible thermoregulatory responses, and do not in themselves represent an adverse health effect. Similarly, although not considered an adverse health effect, behavioral changes to reduce body temperature have also been observed in non-human primates at a whole body average SARs of 1 W kg^{-1}, with the threshold the same for acute, repeated exposures and for long-term exposures.

There is limited epidemiological research on higher cognitive function. There have been reports of subtle changes to performance measures with radiofrequency EMF, but findings have been contradictory and alternative explanations for observed effects are plausible.

[1] Further details concerning the term ‘substantiated’ can be found in the main guidelines document.

In summary, there is no substantiated experimental or epidemiological evidence that exposure to radiofrequency EMF affects higher cognitive functions relevant to health.

2.2. Symptoms and wellbeing

There is research addressing the potential for radiofrequency EMF to influence mood, behavior characteristics and symptoms.

A number of human experimental studies testing for acute changes to wellbeing or symptoms are available, and these have failed to identify any substantiated effects of exposure. A small portion of the population attributes non-specific symptoms to various types of radiofrequency EMF exposure; this is referred to as Idiopathic Environmental Intolerance attributed to EMF (IEI-EMF). Double-blind experimental studies have consistently failed to identify a relation between radiofrequency EMF exposure and such symptoms in the IEI-EMF population, as well as in healthy population samples. These human experimental studies provided evidence that 'belief about exposure' (e.g. the so-called 'nocebo' effect), and not exposure itself, is the relevant symptom determinant.

Epidemiological research has addressed potential long-term effects of radiofrequency EMF exposure from fixed site transmitters and devices used close to the body on both symptoms and well-being, but with a few exceptions these are cross-sectional studies with self-reported information about symptoms and exposure. Selection bias, reporting bias, and nocebo effects are of concern in these studies. In studies on transmitters, no consistent associations between exposure and symptoms or well-being were observed when objective measurements of exposure were made, or when exposure information was collected prospectively. In studies on mobile phone use, associations with symptoms and problematic behavior have been observed. However, these studies can generally not differentiate between potential effects from radiofrequency EMF exposure and other consequences of mobile phone use, such as sleep deprivation in adolescents using the mobile phone at night. Overall, the epidemiological research does not provide evidence of a causal effect of radiofrequency EMF exposure on symptoms or well-being.

However, there is evidence that radiofrequency EMF, at sufficiently high levels, can cause pain. Walters et al. (2000) reported a pain threshold of 12.5 kW m^{-2} for 94 GHz, 3-second exposure to the back, which raised temperature at a rate of 3.3 °C per second (from 34 °C to 43.9 °C). This is similar to that found for heating due to sources other than EMF, where 'weak to moderate' pain was reported for smaller temperature elevations (+4 °C) but with a similar rate of temperature elevation (4 °C per second; Green & Akirav, 2010). However, as Walters et al. used an exposure scenario more relevant to radiofrequency EMF, and as Green and Akirav (2010) has not been replicated (which is particularly important here due to the methodological difficulties associated with self-report measures), it is difficult to determine the relevance of 'rate of temperature elevation' to human health at present.

Another instance of pain induced by radiofrequency EMF is due to 'indirect' exposure via contact currents, where radiofrequency EMF in the environment is redirected via a conducting object to a person, and the resultant current flow, dependent on frequency, can stimulate nerves, cause pain and/or damage tissue. Thresholds are very difficult to determine, with the best estimates of thresholds for health effects being for pain, which is approximately 10 and 20 mA for children and adults respectively (extrapolated from Chatterjee et al., 1986). There is thus no evidence that high frequency EMF exposure affects symptoms, except for pain (and potentially tissue damage) at high exposure levels.

In summary, no reports of adverse effects on symptoms and wellbeing have been substantiated, except for pain, which is related to elevated temperature at high exposure levels. Thresholds for

these have not been clearly identified, but the best estimate is within the vicinity of 10 and 20 mA for indirect contact currents, for children and adults respectively, and 12.5 kW m^{-2} for direct millimeter-wave exposure.

2.3. Other brain physiology and related functions

A number of studies of physiological functions that could in principle lead to adverse health effects have been conducted, primarily using *in vitro* techniques. These have included multiple cell lines and assessed such functions as intra- and intercellular signaling, membrane ion channel currents and input resistance, Ca^{2+} dynamics, signal transduction pathways, cytokine expression, biomarkers of neurodegeneration, heat shock proteins, and oxidative stress-related processes. Some of these studies also tested for effects of co-exposure of radiofrequency EMF with known toxins. Although some effects have been reported for some of these endpoints, there is currently no evidence of effects relevant to human health. There have been some reports of morphological changes to cells, but these have not been replicated, and their relevance to health has not been demonstrated. There have also been reports of radiofrequency fields inducing leakage of albumin across the blood-brain barrier, but due to methodological limitations of the studies and failed attempts to independently replicate the results, there remains no evidence of an effect.

Intense pulsed low frequency electric fields (with radiofrequency components) can cause cell membranes to become permeable, allowing exchange of intra- and extra-cellular materials (Joshi and Schoenbach, 2010); this is referred to as electroporation. 18 GHz continuous wave exposure can result in a similar effect (Nguyen et al., 2017). These require very high field strengths (e.g. 10 kV m^{-1} (peak) in tissue in terms of the former, and 5 kW kg^{-1} for the latter). These levels have not been shown to adversely affect health in realistic exposure scenarios in humans, and given their very high thresholds, are protected against by limits based on effects with lower thresholds and are not discussed further.

Animal studies have also reported that the heating that results from radiofrequency EMF exposure may lead to formation of cataract in rabbits. In order for this to occur, very high local SAR levels (100 – 140 W kg^{-1}) at low frequencies (< 6 GHz) are needed, with increases of several degrees centigrade maintained for several hours. However, the rabbit model is more susceptible to cataract formation than primates (with primates more relevant to human health), and cataracts have not been found in primates exposed to radiofrequency fields. No substantiated effects on other deep structures of the eye have been found (e.g. retina, lens or iris). However, rabbits can be a good model for damage to superficial structures of the eye at higher frequencies (30-300 GHz), because the shape of the facial structure is less relevant to exposure in the more superficial tissue that receives the highest exposure at higher frequencies. However, as the baseline temperature of the anterior portion of the eye (including the cornea) is relatively low (compared with the posterior portion of the eye that would be exposed at lower frequencies), very high exposure levels are required to cause harm superficially. For example, Kojima et al. (2018) reported that adverse health effects to the cornea can occur at > 1.4 kW m^{-2} across frequencies from 40 to 95 GHz, and no effects were found below 500 W m^{-2}; the authors concluded that the blink rates in humans would preclude such effects in humans.

In summary, there is no evidence of effects of radiofrequency EMF on physiological processes or eye pathology that impair health in humans. Some evidence of superficial eye damage has been shown in rabbits at exposures of at least 1.4 kW m^{-2}, although the relevance of this to humans has not been demonstrated.

3. AUDITORY, VESTIBULAR, AND OCULAR FUNCTION

A number of animal and some human studies have tested for potential effects of radiofrequency EMF on function and pathology of these systems.

Sub-millisecond pulses of radiofrequency EMF can result in audible sound. Specifically, within the 200-3000 MHz range the *microwave hearing effect* can result from brief (approximately 100 µs) radiofrequency pulses to the head, which cause thermoelastic expansion that is detected by sensory cells in the cochlea via the same processes involved in normal hearing. This effect is perceived as a brief low-level noise, often described as a 'click' or 'buzzing'. The most recent report has provided a specific absorption (SA) value of 4.5 mJ kg^{-1} per pulse to reach the 20 mPa auditory sound pressure threshold at the cochlea for 10 and 20 µs pulses at 2.45 GHz, which by definition is barely audible (Roschmann, 1991). This equates to a temperature rise of approximately 1 x 10^{-6} °C per pulse. There is no evidence that the microwave hearing effect can affect health, and so the present Guidelines do not provide a restriction to specifically account for microwave hearing.

A few studies reported effects of mobile phone emissions on auditory function and cellular structure in animal models. However, results are inconsistent, and no association of radiofrequency EMF exposure with risk of tinnitus, hearing impairment or vestibular dysfunction has been substantiated in epidemiological studies. Human laboratory studies also failed to identify any adverse health effects of exposure.

A number of experimental human studies have tested for changes to normal sensory processing due to radiofrequency EMF exposure. These have largely been conducted at exposure levels within the ICNIRP (1998) basic restriction levels, and although there are some reports of effects in both categories of research, the results are highly variable, with the larger and more methodologically rigorous studies failing to find such effects.

There is very little epidemiological research addressing sensory effects of devices that emit radiofrequency EMF. The available research has focused on mobile phone use and does not provide substantiated evidence that this is associated with increased risk of tinnitus, hearing impairment, vestibular or ocular function.

In summary, no effects on auditory, vestibular, or ocular function relevant to human health have been substantiated.

4. NEUROENDOCRINE SYSTEM

A small number of human studies have tested whether indices of endocrine system function are affected by radiofrequency EMF exposure. Several hormones, including melatonin, growth hormone, luteinising hormone, cortisol, epinephrine and norepinepherine have been assessed, but no consistent evidence of effects of exposure has been observed.

In animal studies, robust changes have only been reported from acute exposures with whole body SARs in the order of 4 W kg^{-1}, which result in core temperature rises of 1 °C or more. However, there is no evidence that this corresponds to an impact on health. Although there have been a few studies reporting field-dependent changes in some neuroendocrine measures, these have also not been substantiated. The literature as a whole reports that repeated, daily exposure to mobile phone signals does not impact on plasma levels of melatonin or on melatonin metabolism, oestrogen or testosterone, or on corticosterone or adrenocorticotropin in rodents under a variety of conditions.

The two epidemiological studies on potential effects of exposure to radiofrequency EMF on melatonin levels had conflicting results, and both had methodological limitations, including

possible nocebo effects. For other hormonal endpoints no epidemiological studies of sufficient scientific quality have been identified.

In summary, the lowest level at which an effect of radiofrequency EMF on the neuroendocrine system has been observed is 4 W kg^{-1} (in rodents and primates), but there is no evidence that this translates to humans or is relevant to human health. No other effects have been substantiated.

5. NEURODEGENERATIVE DISEASES

No human experimental studies exist for neurodegenerative diseases.

Although one group has reported that exposure to pulsed radiofrequency EMF fields increased neuronal death in rats, which might contribute to an increased risk of neurodegenerative disease, two studies have failed to confirm these results. Some other effects have been reported (e.g. changes to neurotransmitter release in the cortex of the brain, protein expression in the hippocampus, and autophagy in neurons which was not accompanied by apoptosis), but such changes have not been shown to lead to neurodegenerative disease. Other studies investigating effects on neurodegeneration are not informative due to methodological or other shortcomings.

A Danish epidemiological cohort study has investigated potential effects of mobile phone use on neurodegenerative disorders, and reported reduced risk estimates for Alzheimer disease, vascular and other dementia, and Parkinson disease. These findings are likely to be the result of reverse causation, as prodromal symptoms of the disease may prevent persons with early symptoms to start using a mobile phone. Results for multiple sclerosis are inconsistent, with no effect observed among men, and a borderline increased risk in women, but with no consistent exposure-response pattern.

In summary, no adverse effects on neurodegenerative diseases have been substantiated.

6. CARDIOVASCULAR SYSTEM, AUTONOMIC NERVOUS SYSTEM, AND THERMOREGULATION

As described above, radiofrequency EMF can induce heating in the body. Although humans have a very efficient thermoregulatory system, too much heat puts the cardiovascular system under stress and may lead to adverse health effects.

Numerous human studies have investigated indices of cardiovascular, autonomic nervous system, and thermoregulatory function, including measures of heart rate and heart rate variability, blood pressure, body, skin and finger temperatures, and skin conductance. Most studies indicate there are no effects on endpoints regulated by the autonomic nervous system. The relatively few reported effects of exposure were small and would not have an impact on health. The changes were also inconsistent and may be due to methodological limitations or chance. With exposures at higher intensities, up to a whole body SAR of about 1 W/kg (Adair, Mylacraine and Cobb, 2001b), sweating and cardiovascular responses occurred similar to that observed under increased heat load from other sources. The body core temperature increase was generally less than 0.2 °C. The maximal increase in skin temperature of the exposed area observed with 2450 MHz was less than 4 °C at a whole body SAR of approximately 1 W kg^{-1}, which again does not represent an adverse health effect. With exposures to 100 and 250 MHz leading to a whole body average SAR of 0.68 W kg^{-1}, hot spots occurred in the skin of the ankles with an average temperature increase of up to 4 °C (Adair et al., 2005). However, reports of effects that are sufficient to impact on health have not been substantiated.

The situation is different for animal research, in that far higher levels of exposure have been used, often to the point where thermoregulation is overwhelmed and temperature increases to

the point where death occurs. For example, Frei et al. (1995) exposed rats to 13 W kg^{-1} 35 GHz fields, which raised body core temperature by 8 °C (to 45 °C), resulting in death. Similarly, Jauchem and Frei (1997) exposed rats to 13.2 W kg^{-1} 350 MHz fields, and reported that thermal breakdown (i.e. where the thermoregulatory system cannot cope with the increased body core temperature) occurred at approximately 42 °C. These are serious adverse health effects that need to be avoided, however there is not sufficient research using lower exposures to evaluate the threshold for health effects in rodents. It is also difficult to relate these animal findings to humans, as humans are more-efficient thermoregulators than rodents, and thus their thermoregulatory systems can deal effectively with higher exposure levels than rodents. Taberski et al. (2014) reported that in hamsters, no body core temperature elevation is seen at 4 W kg^{-1}, with the only detectable effect a reduction on food intake (which is consistent with reduced eating in humans when warmer).

Few epidemiological studies on cardiovascular, autonomic nervous system, or thermoregulation outcomes are available. Those that are have not demonstrated a link between radiofrequency EMF exposure and measures of cardiovascular health.

In summary, no effects on the cardiovascular system, autonomic nervous system, or thermoregulation that compromise health have been substantiated for exposures with whole body average SARs below approximately 1 W kg^{-1}, and there is some evidence that 4 W kg^{-1} is not sufficient to alter body core temperature in hamsters. However, there is strong evidence that whole body exposures in rats that are sufficient to increase body core temperature by several degrees centigrade can cause serious adverse health effects in rats.

7. IMMUNE SYSTEM AND HAEMATOLOGY

There have been inconsistent reports of transient changes in immune function and haematology following radiofrequency EMF exposures. These have primarily been from *in vitro* studies, although some *in vivo* animal studies have also been conducted. There is currently no evidence that such reported effects, if real, are relevant to human health.

The few human studies have not indicated any evidence that radiofrequency EMF affects health in humans via the immune system or haematology.

8. FERTILITY, REPRODUCTION, AND CHILDHOOD DEVELOPMENT

There is very little human experimental research addressing possible effects of radiofrequency EMF exposure on reproduction and development. What is available has focused on hormones that are relevant to reproduction and development, and as described in the Neuroendocrine System section above, there is no evidence that they are affected by radiofrequency EMF exposure. Other research has addressed this issue by looking at different stages of development (on endpoints such as cognition and brain electrical activity), in order to determine whether there may be greater sensitivity to radiofrequency fields during these stages. There is currently no evidence that developmental phase is relevant to this issue.

Numerous animal studies have shown that exposure to radiofrequency EMF associated with a significant temperature increase can cause effects on reproduction and development. These include increased embryo and fetal losses, increased fetal malformations and anomalies, and reduced fetal weight at term. Such exposures can also cause a reduction in male fertility. However, extensive, well performed studies have failed to identify developmental effects at whole body average SAR levels up to 4 W kg^{-1}. In particular, a large four-generation study on fertility and development using SAR levels up to 2.34 W kg^{-1} found no evidence of adverse effects (Sommer et al., 2009). Some studies have reported effects on male fertility at exposure

levels below this value, but these studies have had methodological limitations, and reported effects have not been substantiated.

Epidemiological studies have investigated various aspects of male and female infertility and pregnancy outcomes in relation to radiofrequency EMF exposure. Some epidemiological studies found associations between radiofrequency EMF and sperm quality or male infertility, but taken together, the available studies do not provide strong evidence for an association with radiofrequency EMF exposure as they all suffer from limitations in study design or exposure assessment. A few epidemiological studies are available on maternal mobile phone use during pregnancy and potential effects on child neurodevelopment. There is no substantiated evidence that radiofrequency EMF exposure from maternal mobile phone use affects child cognitive and psychomotor development, or causes developmental milestone delays.

In summary, no adverse effects of radiofrequency EMF exposure on fertility, reproduction or development relevant to human health have been substantiated.

9. CANCER

There is a large body of literature concerning cellular and molecular processes that are of particular relevance to cancer. This includes studies of cell proliferation, differentiation and apoptosis-related processes, proto-oncogene expression, genotoxicity, increased oxidative stress, and DNA strand breaks. Although there are reports of effects of radiofrequency EMF on a number of these endpoints, there is no substantiated evidence of health-relevant effects.

A few animal studies on the effect of radiofrequency EMF exposure on carcinogenesis have reported positive effects, but in general, these studies either have shortcomings in methodology or dosimetry, or the results have not been replicated in independent studies. Indeed, the great majority of studies have reported a lack of carcinogenic effects in a variety of animal models. A replication of a study in which exposure to radiofrequency EMF increased the incidence of liver and lung tumors in an animal model with prenatal exposure to the carcinogen ENU (ethylnitrosourea) indicates a possible promoting effect (Lerchl et al., 2015; Tillmann et al., 2010). The lack of a dose-response relationship, as well as the use of an untested mouse model for liver and lung tumors whose relevance to humans is uncertain (Nesslany et al., 2015), makes interpretation of these results and their applicability to human health difficult, and therefore there is a need for further research to better understand these results.

A recent, large animal study, performed by the US National Toxicology Program (NTP) reported an increased rate of cardiac schwannoma in male rats exposed to radiofrequency EMF, but not in female rats or either male or female mice (NTP 2018). As the exposure was approximately 75 times higher than the ICNIRP (1998) whole body average general public limit, the results are not directly relevant to radiofrequency EMF levels that humans would typically be exposed to. Further, humans are far more efficient at diminishing the resultant body core temperature rise than rats. As noted by the internal NTP review (NTP 2018), there are also a number of methodological issues that limit the usefulness of the results for EMF health assessment. Of particular note is that the statistics were not able to determine whether the higher number of cardiac schwannomas that were reported was more than what would be expected by chance alone (given that no control for multiple comparisons was applied). This is particularly important given that a graded dose-response relation was not found, no consistency across rodent species or genders was found, and the results are not consistent with the radiofrequency EMF cancer literature more generally. A similar study that was conducted concurrently with the NTP study reported that they had replicated these NTP results on cardiac schwannoma (Falcioni et al., 2018). However, similar to the NTP study, the statistics were also not designed to determine whether the increase was higher than would be expected by chance alone (due to uncorrected multiple statistical comparisons). The schwannoma findings in these

two studies are inconsistent in terms of the exposure-response association as the Italian study observed an 'increased' number of schwannomas at low exposure levels where no increase in schwannoma was observed in the NTP study. These studies therefore do not provide sufficient evidence to conclude that radiofrequency EMF can cause cancer.

A large number of epidemiological studies of mobile phone use and cancer risk have also been performed. Most have focused on brain tumors, acoustic neuroma and parotid gland tumors, as these occur in close proximity to the typical exposure source from mobile phones. However, some studies have also been conducted on other types of tumors, such as leukaemia, lymphoma, uveal melanoma, pituitary gland tumors, testicular cancer, and malignant melanoma. With a few exceptions, the studies have used a case-control design and have relied on retrospectively collected self-reported information about mobile phone use history. Only two cohort studies with prospective exposure information are available. Several studies have had follow-ups that were too short to allow assessment of a potential effect of long-term exposure, and results from case-control studies with longer follow-up are not consistent.

The large, IARC coordinated, Interphone study did not provide evidence of a raised risk of brain tumors, acoustic neuroma or parotid gland tumors among regular mobile phone users, and the risk estimates did not increase with longer time since first mobile phone use (Interphone, 2010; 2011). It should be noted that although somewhat elevated odds ratios were observed at the highest level of cumulative call time for acoustic neuroma and glioma, there were no trends observed for any of the lower cumulative call time groups, with among the lowest risk estimates in the penultimate exposure category. This, combined with the inherent recall bias of such studies, does not provide evidence of an increased risk. Similar results were observed in a Swedish case-control study of acoustic neuroma (Pettersson et al., 2014). Contrary to this, a set of case-control studies from the Hardell group in Sweden report significantly increased risks of both acoustic neuroma and malignant brain tumors already after less than five years since the start of mobile phone use, and at quite low levels of cumulative call time. However, they are not consistent with trends in brain cancer incidence rates from a large number of countries or regions, which have not found any increase in the incidence since mobile phones were introduced.

Furthermore, no cohort studies (which unlike case-control studies are not affected by recall or selection bias) report a higher risk of glioma, meningioma or acoustic neuroma among mobile phone subscribers, or when estimating mobile phone use through prospectively collected questionnaires. Studies of other types of tumors have also not provided evidence of an increased tumor risk in relation to mobile phone use. Only one study is available on mobile phone use in children and brain tumor risk. No increased risk of brain tumors was observed.

Studies of exposure to environmental radiofrequency EMF fields, for example from radio and television transmitters, have not provided evidence of an increased cancer risk either in children or in adults. Studies of cancer in relation to occupational radiofrequency EMF exposure have suffered substantial methodological limitations and do not provide sufficient information for the assessment of carcinogenicity of radiofrequency EMF fields. Taken together, the epidemiological studies do not provide evidence of a carcinogenic effect of radiofrequency EMF exposure at levels encountered in the general population.

In summary, no effects of radiofrequency EMF on cancer have been substantiated.

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