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Letter to the Editor

Opinion on Potential Health Effects of Exposure to Electromagnetic Fields

Scientific Committee on Emerging Newly Identified Health Risks*

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In January 2015, the Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) published its final opinion on "Potential health effects of exposure to electromagnetic fields." The purpose of this document was to update previous SCENIHR opinions in the light of recently available information since then, and to give special consideration to areas that had not been dealt with in the previous opinions or in which important knowledge gaps had been identified. Bioelectromagnetics. 36:480–484, 2015. © 2015 Wiley Periodicals, Inc.

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The European Commission's Independent Scientific Committee on Newly Emerging Environmental Health Risks (SCHENIR) published its final opinion on "Potential health effects of exposure to electromagnetic fields (EMF)" [SCENIHR, 2015] earlier this year. This updates the SCENIHR opinions "Health effects of exposure to EMF" [SCENIHR, 2009a] and "Research needs and methodology to address the remaining knowledge gaps on the potential health effects of EMF" [SCENIHR, 2009b] in light of newly available information. Special consideration was given to areas where previous knowledge gaps were identified [SCENIHR, 2009b] and additional topics were addressed, including biophysical interaction mechanisms and the potential role of co-exposures to environmental stressors.

English language reports published in international peer-reviewed scientific journals were the main source of information considered for this opinion; other sources included web-based information retrieval and documents from governmental bodies and authorities. The articles had to be evaluated and assessed, which was a major part of the Scientific Committee's task, and only those deemed relevant are commented upon in the opinion. Not all studies identified are included in the opinion, but all identified studies are listed in the annex.

Guidance for assessing sources of information was provided by SCHENIR's "Memorandum on the use of the scientific literature for human health risk assessment purposes—weighing of evidence and expression of uncertainty" [SCENIHR, 2012]. A specific concern in assessment of many studies, experimental as well as epidemiological, was exposure description. Many studies reported biological effects as a result of EMF exposure, but in many cases the exposure description was insufficient for reproducing the experiment. Papers that poorly describe essential data, such as exposure, are of little or no value in risk assessment. In the last few years, there have been a number of in vivo and in vitro studies focused on direct exposure from a commercial mobile phone or other wireless device. In almost all cases, these experiments could not be taken into consideration because they did not quantify factual exposure.

Ideally, an epidemiological study should capture all major sources of exposure as a function of time during the relevant time period (considering latency) prior to occurrence of the outcome. For an epidemiological study to be useful and informative, minimum requirements for exposure assessment are that it must include reasonably accurate individual exposure char-

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acterization over a relevant period of time and must capture all major sources of exposure for the pertinent part of the body. Valid exposure assessment is required to distinguish between sub-groups with contrasting exposure levels. The particular challenge with EMF exposure is that it is ubiquitous, making it difficult to find an unexposed reference group. For that reason, a quantitative contrast is chosen by comparing low versus high exposure levels.

In general, personal exposimetry is regarded as the highest standard for assessment of current short-term exposure, because spot measurements may not adequately reflect long-term exposure. For studies on health risks from EMF, depending on the investigated endpoint, the relevant time period for which exposure data is needed is quite long, for example, up to several years preceding cancer diagnosis. As a rule, retrospective exposure assessment is more challenging and prone to errors than estimating concurrent exposures. Estimates from study subjects are rarely reliable because of potential errors in recall, particularly for case–control studies, so more objective information sources should be used whenever possible.

Besides lacking clearly focused working hypotheses for chosen biological endpoints, research on health effects of EMF suffers from a lack of an established biological or biophysical mechanism of action at environmental exposure levels. This prevents researchers from concluding on the most relevant exposure parameter, and usually several alternative measures of exposure are evaluated (including field strength, exposure frequency, cumulative exposure, time since first exposure, etc.)

Additionally, some studies use multiple endpoints, which are prone to false positive results, without adequate statistical corrections. Good research practice requires all hypotheses evaluated are clearly stated and all results pertaining to them reported. Selective reporting, with emphasis on significant findings that were not specified in advance, can mislead the assessment by ignoring the issue of multiple testing.

Exposure. Humans are exposed to EMF every day from various sources and in many different situations. Presently, man-made static fields are mainly found in occupational settings, such as in proximity to magnetic resonance imaging (MRI) scanners. In the future, more DC high-voltage overhead transmission lines, now under construction, are expected to expose larger parts of the population to static electric and magnetic fields.

In the extremely low frequency (ELF) range, EMF exposure is nearly omnipresent. The general public's main sources of exposure are household appliances, in-house installations and power lines. In recent years, concern has also been raised about people living next to electric power transformers installed inside residential buildings. For these people, long-term exposure to ELF magnetic fields may extend to several tenths of μT. Today's voltage regulation for most modern electrical equipment (including switched power supplies to laptops, drilling tools, mobile phones chargers and other similar devices) uses electronics instead of transformers. As a consequence, frequency content of the daily magnetic field exposure has changed, primarily by the addition of odd harmonics (150, 250, 750 Hz, etc.). In particular, the third harmonic (150 Hz) has become another dominating frequency in our environment. Additionally, more household appliances have appeared in the intermediate frequencies (IF) range. It was found that some of them exceed reference levels set by exposure guidelines at close range. Induction hobs are an important source of exposure in this frequency range and can expose users to IF magnetic fields higher than reference levels of exposure guidelines, mostly because their safety standard is based on users being at a distance of 0.3 m from the hob, which is not always the case.

Most applications that emit EMF are in the frequency range above 100 kHz up to GHz, and people are usually exposed to multiple sources. Main exposure sources are transmitters used near or on the body. Distance to the source is the main determinant of exposure level, along with emitted power and duty factor.

In particular for brain tissues, the mobile phone held at the ear remains the main exposure source. However, since mobile telephones came out on the market, emission power from mobile handsets has been reduced. DECT cordless phones are another source of everyday exposure and together with smart phones, which operate within networks of different technologies, as well as other portable wireless devices like tablets and laptop computers, have added complexity to the user's exposure and changed the exposed body region. Due to different sources used next to the body, multiple source exposure must be taken into account for risk assessment, which may also require organ specific dosimetry. This is important for occupational exposure as well, since in some situations, such as working in an MRI suite, professionals may be exposed simultaneously to EMF of multiple frequencies ranges, different temporal variations and field strengths.

Exposure from environmental sources is mainly from broadcasting antennas, antennas from private and

governmental telecommunication services and mobile communications base stations. Such systems have been shown to significantly increase EMF levels in urban areas compared to levels measured during the 1980s, when only analogue radio and television broadcasting were present. However, historical data from spot measurement campaigns and continuous radiation monitoring systems indicate that the introduction of new mobile telecommunication technologies after the deployment of GSM and UMTS systems did not significantly change average levels of EMF in the environment.

Indoor sources have also increased in number. The installation of access points and short range base stations, such as 3G femtocells, WiFi hotspots and DECT devices, has led to increased exposure at very close distances (within 1 m). Farther away, emitted EMF does not surpass common background levels. As a result, emitted EMF from these devices, even when combined, still results in a marginal exposure compared to reference levels of European and international guidelines. In general, telecommunication applications seem to be moving toward low-power emitters, closer to or on the human body, operating at higher frequencies.

Millimeter wave and THz applications may soon be available in various industrial environments, used for such applications as imaging systems for non-destructive quality control and short-range broadband telecommunications. Currently, they do not significantly affect the general public's average exposure. These applications operate with low power and only expose superficial tissues.

Interaction mechanisms. Several interaction mechanisms are well established. They have been used to formulate guidelines for limiting exposure to EMF in the entire frequency range from static fields to 300 GHz. Various studies reported other candidate mechanisms, but none operating in humans at exposure levels found in the everyday environment has been firmly identified and experimentally validated. These other mechanisms do not, therefore, allow conclusions to be drawn on potential health risks at other exposure conditions with regard to amplitude and/or frequency.

Health effects from THz fields. The number of studies investigating potential biological, non-thermal effects of THz fields is small but increasing due to availability of adequate sources and detectors.

In vivo studies indicate mainly beneficial effects on disorders of intravascular components of microcirculation in rats under immobilization stress, but do not examine acute and chronic toxicity or carcinogenesis. In vitro studies on mammalian cells differ greatly with respect to irradiation conditions and endpoints under investigation. Studies suggesting exposure effects have not been replicated in independent laboratories. Some theoretical mechanisms have been suggested but lack conclusive experimental support. Considering the expected increase in use of THz technologies, more research on the effects on skin (long-term, low-level exposure) and cornea (high-intensity, short-term exposure) is needed.

Health effects from RF fields. Overall, epidemiological studies on mobile phone RF EMF exposure do not show an increased risk of brain tumors. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region. Some studies raised questions regarding increased risk of glioma and acoustic neuroma in heavy users of mobile phones. Results of cohort and incidence time trend studies do not support an increased risk for glioma while the possibility of an association with acoustic neuroma remains open. Epidemiological studies do not indicate increased risk for other malignant diseases, including childhood cancer. A substantial number of well-performed in vivo studies using a wide variety of animal models have produced mostly negative outcomes.

A large number of in vitro studies concerning genotoxic as well as non-genotoxic endpoints have been published since the last opinion. In most studies, no effects of exposure at non-thermal levels were reported, although in some cases DNA strand breaks and mitotic spindle disturbances were observed.

More recent studies substantiate earlier described evidence that RF exposure may affect brain activities as reflected by electroencephalography (EEG) studies during wake and sleep. With regard to these findings, studies that aim at investigating the role of pulse modulation and which use more experimental signals, indicate that although effects on the sleep EEG are neither restricted to non-rapid eye movement (NREM) sleep (one study indicates effects also in REM sleep) nor to the spindle frequency range. It seems that depending on EMF signal, the theta and delta frequency range in NREM sleep can also be affected. Furthermore, half of experimental studies looking at macrostructure of sleep (especially those with a longer duration of exposure) also found effects that are inconsistent with regard to affected sleep parameters. Therefore, given the variety of applied fields, duration of exposure, number of considered leads, and statistical methods it is presently not possible to derive more firm conclusions.

Results are inconsistent for event-related potentials and slow brain oscillations. Furthermore, there is a lack of data for specific age groups. One study indicates that children and adolescents seem to be less affected. Previous evidence [SCENIHR, 2009a] that RF exposure may affect brain activity as reported by EEG studies during both wake and sleep also appears in recent studies. However, the relevance of these small physiological changes remains unclear and no mechanistic explanation has been provided.

Overall, there is a lack of evidence that RF EMF affects cognitive functions in humans. Studies looking at possible effects of RF fields on cognitive function have often included multiple outcome measures. While effects have been found by individual studies, these have typically been observed only in a small number of endpoints, with little consistency between studies.

Symptoms attributed by some people to RF EMF exposure can sometimes cause serious impairments to a person's quality of life. However, research conducted since the previous SCENIHR opinion [SCENIHR, 2009a] adds weight to the conclusion that RF EMF exposure is not causally linked to these symptoms. This applies to the general public, children and adolescents, and to people with idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF). Recent meta-analyses of observational and provocation data support this conclusion.

For symptoms triggered by short-term exposure to RF fields (measured in minutes to hours), consistent results from multiple double-blind experiments give strong overall evidence that such effects are not caused by RF exposure. For symptoms associated with longer-term exposures (measured in days to months), evidence from observational studies is broadly consistent and weighs against a causal effect. However, there are gaps of knowledge here, most notably in terms of the objective monitoring of exposure.

Human studies on neurological diseases and symptoms show no clear effect, but evidence is limited.

The previous SCENIHR [2009a] opinion concluded that there were no adverse effects on reproduction and development from RF fields at non-thermal exposure levels. Inclusion of more recent human and animal data does not change this assessment. Human studies on child development and behavioral problems had conflicting results and methodological limitations. Therefore, evidence of an effect is weak. Effects of exposure on fetuses from mother's mobile phone use during pregnancy are not plausible due to extremely low fetal exposure. Studies on male fertility are of poor quality and provide little evidence.

Health effects from IF fields. There are few new studies on health effects from IF exposures in general, and no epidemiological studies have been conducted in particular. Some in vivo studies report absence of effects on reproduction and development of IF fields up to 0.2 mT in a frequency range of 20–60 kHz. Given the expected increase of occupational exposure to IF EMF, studies on biomarkers and health outcomes in workers, based on reasonably sized groups with well-characterized exposure, would be very useful and could be supplemented with experimental studies.

Health effects from ELF fields. Overall, existing studies do not provide convincing evidence for a causal relationship between ELF magnetic field (MF) exposure and self-reported symptoms. New epidemiological studies are in line with earlier findings of an increased risk of childhood leukemia with estimated daily average exposures above 0.3–0.4 μT. As stated in the previous opinion [SCENIHR, 2009a], no mechanisms have been identified and no support exists from experimental studies that could explain these findings, which together with limitations of the epidemiological studies, prevent a causal interpretation.

As concluded in the previous SCENIHR [2009a] opinion, data suggest that ELF MF may induce both genotoxic and other biological effects in vitro at magnetic flux densities of about 100 μT and higher. Mechanisms are not established and relevance for a connection between ELF MF exposure and childhood leukemia is unclear. Studies investigating possible effects of ELF exposure on the power spectra of the waking EEG are too heterogeneous with regard to applied fields, duration of exposure, number of considered leads, and statistical methods to draw a sound conclusion, which is also the case for behavioral outcomes and cortical excitability.

Epidemiological studies do not provide convincing evidence of increased risk of neurodegenerative diseases, including dementia, related to ELF MF exposure. Furthermore, they show no evidence for adverse pregnancy outcomes in relation to ELF MF. Studies on childhood health outcomes in relation to maternal residential ELF MF exposure during pregnancy involve some methodological issues that need to be addressed. They suggest implausible effects and need to be replicated independently before they can be used for risk assessment. Recent results do not show that ELF fields have any effect on the reproductive function in humans.

Health effects from static magnetic fields (SMF). In the majority of available in vitro studies, SMF above 30 μT induced effects in cellular endpoints investigated, although effects were transient in some cases. Gene expression was affected in all studies, with predominantly up-regulated outcomes. Findings from these new studies are consistent with previous results.

A number of studies report that effects of SMF exposures occur in animals at levels ranging from mT to T. However, since many findings are limited to single studies, they do not provide a firm foundation for risk assessment.

Observational studies have shown that movement in strong SMF may cause effects like vertigo and nausea, which can explained by established interaction mechanisms and are more likely to occur in fields above 2 T.

Relevance of these effects on health of personnel remains unclear.

Health effects from combined exposure to different EMF. The few available studies on combined exposure to different EMF do not provide sufficient evidence for risk assessment. It is clearly of interest to follow up on studies concerning effects on DNA integrity after an MRI examination. However, it is unclear which component of the complex EMF exposure during scanning may cause the effect: SMF, switched gradient MF or pulsed RF EMF. Further studies on DNA integrity and MRI exposure are required and the feasibility of cohort studies of MRI patients and occupationally exposed personnel should also be discussed.

Health effects from co-exposure to environmental stressors. Experimental results reported since the previous opinion was published [SCENIHR, 2009a] on co-exposures of environmental stressors (such as physical or chemical agents) with ELF or RF are inconsistent. Under the same conditions, effects might be increased, decreased, or not influenced at all and are not linked to specific experimental protocols. Due to the small number of available investigations and the large variety of protocols used (different chemical or physical treatments and different EMF exposure conditions), it is not possible to draw definitive conclusions. Therefore, relevance of co-exposures of environmental stressors with ELF or RF to human health under real-life exposure conditions remains unclear.

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