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RESEARCH ARTICLE

Health Council of the Netherlands: No need to change from SAR to time-temperature relation in electromagnetic fields exposure limits

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Abstract

The Health Council of the Netherlands (HCN) and other organisations hold the basic assumption that induced electric current and the generation and absorption of heat in biological material caused by radiofrequency electromagnetic fields are the only causal effects with possible adverse consequences for human health that have been scientifically established to date. Hence, the exposure guidelines for the 10 MHz–10 GHz frequency range are based on avoiding adverse effects of increased temperatures that may occur of the entire human body at a specific absorption rate (SAR) level above 4 W/kg.

During the workshop on Thermal Aspects of Radio Frequency Exposure on 11–12 January 2010 in Gaithersburg, Maryland, USA, the question was raised whether there would be a practical advantage in shifting from expressing the exposure limits in SAR to expressing them in terms of a maximum allowable temperature increase. This would mean defining adverse time–temperature thresholds. In this paper, the HCN discusses the need for this, considering six points: consistency, applicability, quantification, causality, comprehensibility and acceptability.

The HCN concludes that it seems unlikely that a change of dosimetric quantity will help us forward in the discussion on the scientific controversies regarding the existence or non-existence of non-thermal effects in humans following long duration, low intensity exposure to electromagnetic fields. Therefore, the HCN favours maintaining the current approach of basic restrictions and reference levels being expressed as SAR and in V/m or μT, respectively.

Keywords: *RF exposure, SAR, RF guidelines, thermal effects, non-thermal effects, EMF*

Introduction

Current exposure limits for electromagnetic fields (EMF) in the radiofrequency (RF) range up to 10 GHz are defined as basic restrictions, expressed in the specific absorption rate (SAR), in W/kg, and reference levels derived from the basic restrictions, defined as the strength of the electric field E (in V/m) and the magnetic flux density B (in μT). At the Workshop on Thermal Aspects of Radio Frequency Exposure, held on 11–12 January 2010 in Gaithersburg, Maryland, USA[1], one of the issues discussed was whether there would be a practical advantage in shifting from expressing the exposure limits in the present units to expressing them in

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terms of a maximum allowable temperature increase, which would mean defining adverse time–temperature thresholds. It should be noted that the Institute of Electrical and Electronics Engineers International Committee on Electromagnetic Safety (IEEE ICES) raised the issue of redefining the limits only in the context of partial body exposure. Whole body exposures are explicitly excluded from the discussion as whole body EMF exposure within the present IEEE and International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines will hardly result in any temperature increase due to the effective thermo-regulation mechanisms.

In this paper the Electromagnetic Fields Committee of the Health Council of the Netherlands (HCN) presents its view on this issue.

Current position of the Committee regarding health effects of EMF

Thermal effects

In its 1997 guidelines for exposure limits, the HCN considered that for the RF frequency range (10 MHz–300 GHz) the only health effects that have been scientifically established are those resulting from the induction of current and/or the generation and absorption of heat in biological material caused by RF EMF [1]. Other organisations such as ICNIRP and IEEE have come to the same conclusions [2, 3]. The basic premise is that core body temperature should not increase for long periods by more than 1°C. To achieve this, the SAR averaged over the entire human body should not exceed 4 W/kg. A SAR of 4 W/kg is also the threshold reported for behavioural changes in animals [4, 5]. If only parts of the body are exposed, a higher SAR is acceptable, since the excess heat will be removed from the exposed site by the blood circulation (which is much less the case when the entire body is exposed).

Non-thermal effects

There is an ongoing debate whether effects other than those associated with the generation of heat might be occurring, and if so, whether they lead to adverse health effects. In several studies, in both *in vitro* animal and human studies, effects of RF EMF exposure have been observed that most likely cannot be explained by temperature changes. However, it has not been convincingly demonstrated that short-term non-thermal biological effects of RF EMF may result in short-term or long-term adverse health effects in humans.

As the HCN has indicated, there is a distinction between biological effects and health effects [6]. The human body has a large capacity to compensate for a variety of effects induced by external or internal sources. Only when the limits of this compensation are exceeded, may health problems arise. For electric or magnetic fields to cause health effects, they must first interact with biological molecules or structures and induce a change by transferring energy. Subsequently, this must cause individual cells to produce a collective response of the organism that extends beyond the physiological range of resilience that the organism can normally handle without any harmful effect. Furthermore, organisms are also capable of physiological adaptation. If these mechanisms were not present, the average life span would be considerably shorter than it currently is; as in everyday life, organisms are continually exposed to artificial, but also to natural potentially harmful substances, non-ionising and ionising radiation and threats of a biological nature. A biological effect does not always, therefore, result in a detrimental health effect.

An important question in relation to possible non-thermal health effects is, whether there are indications for the existence of a causal relationship between exposure to RF EMF and the development of cancer. In its 2008 Annual Update the HCN concluded that the available data provided no indication for the existence of a causal relationship between the incidence of cancer and low-level, long-duration exposure to RF EMF [6].

Another important issue is that a large range of often non-specific health problems is frequently attributed to exposure to RF EMF generated by mobile telecommunication base stations or mobile phones [6]. Examples of such complaints are headache, insomnia and concentration problems. The HCN acknowledges the existence of such symptoms but notes that a variety of causes could play a role. From the available scientific evidence the HCN concluded that there is no scientific proof to date of any causal relationship between EMF exposure and the occurrence of these symptoms. There is, however, an association between the conscious expectation of exposure and non-specific health problems [6–9].

The HCN considers that the scientific evidence is inadequate to reasonably defend that any of the three categories of non-thermal effects – biological effects, carcinogenesis and non-specific health complaints – should lead to adaptation of RF EMF exposure limits. Therefore the HCN adheres to the exposure limits proposed in its 1997 report [1].

Public concern regarding health effects of EMF

The growth in wireless applications causes a changing pattern of exposure. Some 20 years ago, radio and television transmitters and the electricity supply network were the main sources of EMF. Nowadays there are many new applications, particularly in the RF part of the spectrum, and more are constantly being introduced. As a result, people are being exposed to all kinds of different signals. This has resulted in an increased overall intensity of exposure, and a changing exposure pattern. The question is whether these new types of signal may result in health effects. As reported by Cousin and Siegrist [10], and also concluded by all formal advisory committees and commissions on non-ionising radiation protection, the consensus scientific view is that there is no convincing scientific evidence for health risks of exposure to RF EMF at levels below those recommended in international guidelines. However, many in the general public do feel that the lack of a clear proof that no health effects exists, is sufficient reason for a strong plea to lower the currently applied exposure limits. This view is supported by the fact that an increasing number of people attributes all kinds of non-specific health complaints – including headache, insomnia and concentration problems – to low intensity, long duration exposure to EMF, and by information provided by the media on low level effects of EMF, often overemphasising the studies showing an effect, while ignoring studies not finding any effect [11]. So far there is no convincing fundamental mechanism described that can fully explain the putative interaction between biological material and EMF at non-thermal levels.

As result of this, a demand has been created by part of the public (and a few of the scientific community) for precautionary measures beyond the current exposure limits. In this respect it is important to notice that in practice the exposure of the general public to environmental EMF is usually far below the current guidelines, and thus not associated with a substantial temperature increase.

RF exposure limits: SAR versus time–temperature thresholds

Is there a practical advantage in changing from expressing the exposure limits for frequencies up to 10 GHz as SAR to expressing them in terms of a maximum allowable temperature increase (i.e. define adverse time–temperature thresholds)? Important aspects in the following discussion are:

- consistency over all frequencies,
- applicability at all circumstances,
- quantification of the exposure parameter (measurement and recall),
- causality,
- comprehensibility,
- acceptability.

Consistency

Uniformity in expressing exposure limits for non-ionising EMF is an important issue which allows a smooth transition of the exposure guidelines over the whole frequency range. For EMF in the extremely low frequency (ELF) range the human body is small compared to the wavelength of the fields. Up to the kHz range little of the energy of the electric or magnetic field is absorbed by tissues, and biological effects, e.g. the stimulation of nerves or muscles, result from currents that are induced by the fields. With increasing frequency there is a gradual shift from induction of electric currents to absorption of EMF energy as most dominant interaction mechanism. For frequencies between 100 kHz and 10 MHz both the density of the induced electric current and the SAR are considered as relevant dosimetric quantities and need to be assessed. Between 10 MHz and 10 GHz the SAR is the dosimetric quantity used. For higher frequencies ranging up to the infrared and ultraviolet, superficial absorption of electromagnetic energy dominates. Therefore for frequencies above 10 GHz the incident power density is the main exposure unit. For ionising radiation the absorbed dose is used as the basis for exposure limits.

Replacing the SAR for frequencies between 10 MHz and 10 GHz by a time–temperature threshold would result in a situation where for a part of the spectrum no longer the absorbed energy but a temperature increase is used as the parameter to regulate permissible exposure. In the opinion of the HCN this will not contribute to clarity in the discussion on 'safe' guidelines.

Applicability

Although applicability and quantification are two closely related issues, they are discussed separately here. As discussed before, the general scientific consensus is that in the 10 MHz–10 GHz range exposure to EMF at levels above the current guidelines may result in adverse health effects caused by thermal effects. This provides a good rationale to consider time–temperature thresholds as a measure for acceptable exposure levels.

However, it will be a very difficult task to implement a time–temperature threshold beyond how it is currently applied, i.e. translating an acceptable temperature increase (1°C) into a limiting energy absorption for a healthy person in good physiological condition. From all the studies presented at the

Workshop it became clear that there is in general a lack of data on time–temperature thresholds for adverse thermal effects in humans [12]. Furthermore, in all experimental studies the time–temperature exposures have been at a level much higher than that occurring during partial or whole body exposure to the EMF of a mobile phone or base station. The latter also applies to cases in which EMF exposure occurs at relatively high intensity levels such as in MRI applications. Even in these situations the aim is to adhere to the IEEE and ICNIRP partial body exposure guidelines and to limit the local temperature increase to a minimum. Subsequently, here again the lack in human data prevents implementation of guidelines based on time–temperature thresholds other than the generic rules as applied in the IEEE and ICNIRP guidelines. Overall, this finding is not surprising, as a substantial thermal dose needs to be applied in order to see an acute thermal effect. Only in the studies observing effects of heat on the immune system, the applied temperature increase is moderate, though still a core temperature of the body of around 39–40°C is common in these experiments [13].

The study on thermoregulation and tolerance of exercise-induced heat in children by Bergeron [14] is relevant in this respect, since it is imaginable that children may use their mobile phone shortly after exercise. Bergeron showed that young adults have similar cardiovascular and thermoregulatory capacities as adults and that training, intensity of the exercise and environmental conditions are the relevant parameters in the body's thermal and physiological response [14]. It will be extremely difficult to translate the added absorption of a local and small amount of energy due to a mobile phone call or due to a nearby base station into an additional increase of the body temperature or estimate an acceptable time–temperature threshold for these circumstances.

Quantification

An important point for exposure parameters should be that they can be easily quantified. This is not the case for the SAR, therefore the basic restrictions that govern the current RF exposure guidelines have been converted into reference levels for the electric and magnetic fields that can be measured at the site of the exposure or calculated using sophisticated computer models for more complex exposure configurations. The question is whether the translation from SAR to time–temperature thresholds will result in a better (more accurate and realistic) estimation of the exposed 'dose'. The answer to this question is for the time being certainly negative. At present highly advanced mathematical platforms exist with which the SAR in humans can be predicted with a much higher numerical accuracy than can be obtained by measurement. By using realistic and highly detailed models of humans and of the electromagnetic source (i.e. complete computer aided design drawings of the device under investigation), the SAR distribution in (parts of) the body can be calculated with an appropriate accuracy for all kinds of different exposure conditions. The next step, i.e. translating the SAR distribution into a temperature distribution, is much harder to achieve and substantially less accurate. The temperature increase resulting from the energy absorption will depend strongly on the local blood perfusion and on cooling of the tissue through conduction and convection to the environment. All these parameters are dependent on the initial temperature of the human body and will vary substantially according to the conditions, making temperature predictions insufficiently reliable.

For experimental studies one may implement a number of more or less strict experimental limitations to overcome the above problems, or at least report their impact as an uncertainty in the predicted time–temperature exposure. In epidemiological studies it seems a mission impossible to estimate the dose in terms of time–temperature effects. Already in current studies recall bias in the use of the mobile phone is one of the most important factors in limiting the assessment of exposure-effect relationships. If time–temperature thresholds would be used, the participants in an epidemiological study would not only have to recall the position of the phone more accurately, but would also have to recall the environmental conditions during the exposure and on top of that should also have to remember their health status, as the biological effect of a temperature increase depends on the base line temperature.

Causality

The causality between the current basic restrictions that are based on the premise to limit the whole body temperature increase to 1°C and the related reference levels is without discussion. However, the relation between thermal dose expressed as time–temperature exposure and biological effects is not as clear and trivial as one may expect. The presentations at the workshop indicated that heating of tissue causes a multitude of biological effects that are not only time and temperature dependent, but also there seems to exist a thermal threshold for certain effects (e.g. increased perfusion). Furthermore, it is unclear when, depending on exposure time and volume involved, the response to a local heat load (i.e. partial exposure) moves from a local to a systemic tissue reaction. The probability that such thermal effects might be induced at the time–temperature levels

as occurring during exposure to EMF at levels below the current guidelines might be extracted from the various contributions to this volume. In general, for effects to occur, exposure of long duration is required at the relatively mild temperature increase up to 39–40°C or exposure of shorter duration with higher temperature increases. Such conditions are not representative, however, for the exposure of the general public to RF EMF, and in fact not even for occupational exposure up to the current exposure guidelines. Again, even under conditions with higher exposure levels as in MRI examinations the strategy is to keep local temperature increases below 1°C and certainly avoid such exposures for long durations.

Comprehensibility

There is no doubt that in general people will better understand an acceptable dose that is expressed in temperature increase for a certain period of time, than one that is expressed in SAR or an exposure level expressed in V/m or μT. However, improving the understanding by laypeople of the nomenclature of dosimetric quantities should not aim at the general public that has no concerns, but at those people, including self-proclaimed electrohypersensitives, who fear non-thermal effects of electromagnetic fields. For these groups, and more specifically for the most vocal individuals of them, it seems fair to assume that they have educated themselves and are familiar with the concepts of SAR, V/m and μT.

Acceptability

A final important issue is whether the proposed change will be found acceptable by the public and by those opposing the current exposure guidelines. Why should they? The claim of the stakeholders in favour of lowering the current guidelines is not that thermal effects do not exist, they agree with that, but their concern focuses on the potential health risks of exposure to electromagnetic fields at the level below those recommended in international guidelines.

On the other hand what is the interest for the stakeholders (i.e. advisory committees, commissions on non-ionising radiation protection and industry) to convert the current guidelines to those built on time–temperature thresholds? In the current setting the latter group has already made clear statements that their consensus is that there is only convincing scientific evidence for health risks of exposure to electromagnetic fields at the levels producing a thermal effect, i.e. above the levels recommended in international guidelines.

Discussion

The HCN and other organisations hold the basic assumption that the development of heat in biological material caused by RF EMF is the only health effect that has been scientifically established. Hence, the exposure guidelines for the 10 MHz–10 GHz frequency range are based on avoiding adverse effects of increased temperatures that may occur with exposures of the entire human body at a SAR level above 4 W/kg. Clearly, the HCN has no objection against experimental or human research which results in a more detailed and accurate definition of time–temperature threshold for thermal damage (for instance organ-specific).

In response to the question whether there are reasons to replace the dosimetric quantity of SAR with a time–temperature threshold, the HCN has considered six items: consistency, applicability, quantification, causality, comprehensibility and acceptability. Overall, the HCN concludes that it seems unlikely that a change of dosimetric quantity will help us forward in the discussion on the scientific controversies regarding the existence or non-existence of non-thermal effects in humans following long duration, low intensity exposure to EMF. Therefore, the Committee favours maintaining the current approach of basic restrictions and reference levels being expressed as SAR and in V/m or μT, respectively.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Note

1. Co-hosted by the US Food and Drug Administration (FDA), the Mobile Manufacturers Forum (MMF), and the GSM Association (GSMA).

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