Bundesamt
für Strahlenschutz

Spotlight on EMF Research

Spotlight on “Excessive whole-body exposure to 28 GHz quasi-millimeter wave induces thermoregulation accompanied by a change in skin blood flow proportion in rats” by Ijima et al. in Frontiers in Public Health (2023)

Category [radiofrequency, animal study]

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Competence Centre Electromagnetic Fields (KEMF)

1 Putting the paper into context by the BfS

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) [2] and the IEEE International Commission on Electromagnetic Safety (ICES) [3] recommend limits to restrict individual exposure to electromagnetic (EM) fields. For frequencies above 6 GHz in the EM spectrum, “basic restrictions” are specified for the specific energy absorption rate (SAR) averaged over the whole body and for the local absorbed power density (APD) in the tissue. Ensuring compliance with these limits is crucial to prevent excessive, exposure-related increases in core body and localised tissue temperatures. The basic restrictions are established with careful consideration of reduction factors. These reduction factors ensure that, even at maximum permissible exposure levels, “operational thresholds” for temperature increases capable of triggering adverse health effects are not exceeded. These thresholds correspond to temperature increases of 5 °C and 2 °C for localised exposure of different tissue types and of 1 °C for whole-body exposure. The phenomenon of thermoregulation has not been sufficiently taken into account in the development of limit recommendations due to an insufficient database. The results of the present study, which investigates the thermoregulation of exposed rats, could be used in future discussions for further development of limit concepts.

2 Results and conclusions from the authors‘ perspective

Ijima et al. conducted the present study [1] to improve knowledge of the mechanism of thermoregulation during EM field exposure for the purpose of setting exposure limits. It involves an in vivo experiment on rats continuously exposed to EM fields at a frequency of 28 GHz (quasi-millimetre waves), which is a frequency intended for the fifth generation of mobile communications (5G). Each animal was placed in an

acrylic holder 50 cm below a lens antenna directed at the shaved back and exposed to antenna input powers of 0 W (8 rats, sham exposure), 14 W (11 rats) and 28 W (12 rats). Whole-body SAR and local APD values were determined using finite-difference time-domain (FDTD) numerical field simulations. During the 40 minutes exposure (and 4 minutes before), time-dependent temperature changes were measured with fibre-optic thermometers in the rectum, in the dorsal skin and at the base of the tail of the rats. Blood flow, which is involved in thermoregulation through convective transport of heat in the body, was measured using a Doppler blood flow meter in the dorsal skin and at the base of the tail. The times after which a statistically significant exposure-related change in temperature and blood flow occurred were determined.

Dorsal skin temperature increased for both antenna input powers a few seconds after the start of exposure. It took up to several minutes for rectal and tail temperatures to increase to statistically significant levels. However, at 28 W antenna input power, the maximum temperature increase in the tail was about 8 °C, twice that of the dorsal skin. Blood flow in the dorsal skin did not change. In the tail, blood flow increased approximately linearly until the end of exposure.

The basic restrictions for the whole-body SAR and the local APD in the limit recommendations [1] were derived from computer simulations using numerical tissue models. However, it is not known which maximum levels of the whole-body SAR and the local APD at frequencies above 6 GHz lead to defined and, according to current knowledge, still harmless temperature changes in living animals and humans. Therefore, Ijima et al. first formulated the dependencies of the measured temperature changes on the local APD (temperature measurement on the back) and on the whole-body SAR (temperature measurements in the rectum and on the tail) in the form of linear regression models. This was used to estimate the whole-body SAR and the local APD values associated with temperature increases of 1 °C and 5 °C in the respective body areas (back, rectum, tail) at exposure times of 6, 12 and 30 minutes. Accordingly, at 488 W/m², more than twice the local APD (compared with 200 W/m² in a numerical simulation using a model of human skin [5]) is required to heat the dorsal skin of a rat by 5 °C during a six-minute exposure. A whole-body SAR of 4.6 W/kg is required to raise the rectal temperature of a rat by 1 °C during a 30-minute exposure. This is in good agreement with a whole-body SAR of 4 W/kg, which – based on a numerical whole-body model of a human – causes an increase in core body temperature of 1 °C.

Two possible adverse effects in rats after 30 minutes exposure are derived from the available results:

1. A local APD of more than 291 W/m² could result in thermal damage to deep layers of the directly irradiated skin, as a critical temperature of 41.9 °C would be exceeded [6].
2. Exposure to a whole-body SAR of 38 W/kg caused the rectal temperature to rise to 42 °C. Such an increase in colonic temperature can lead to a sharp drop in arterial blood pressure and subsequent death of the animal [7, 8, 9].

The dissipation of heat, absorbed by the body, through the tail into the environment was modelled using three linear relationships. First, the increase in rectal temperature was estimated as a function of the whole-body SAR. Temperature variations during sham exposure were eliminated from the corresponding linear equations. From the second linear relationship between rectal temperature and tail blood flow ("thermoregulatory model-1"), tail temperature could be modelled using the third linear equation ("thermoregulatory model-2"). Tail temperature estimates from the linear thermoregulation models were in good agreement with the experimentally determined values. Ijima et al. therefore propose a mechanism of thermoregulation in rats in three steps:

1. Exposure-induced heating of tissues close to the body surface accumulates in the body, leading to an increase in core body temperature.
2. This is followed by an increase in blood flow in the tail ("thermoregulatory model-1").
3. The increase in temperature in the tail immediately follows step 2 ("thermoregulatory model-2"), which promotes heat dissipation to the environment.

3 Comments by the BfS

In the present study [1], a novel approach was taken by exposing rats to 28 GHz quasi-millimetre waves. Exposure-induced temperature changes and skin blood flow were measured simultaneously in different regions of the body during the experiments. This approach offers an advantage over other experimental approaches that require interruption of the exposure to determine physiological parameters in the animals, which may lead to stress-related changes in the measurement results or greater uncertainties in the estimation of the exposure-induced temperature increase. A numerical rat model with six anatomical tissues was used to calculate the absorbed radiation power in the rats using computer simulations. This makes it possible to accurately determine the whole-body SAR and local APD values resulting from the exposure. The results of the study provide exciting insights into the mechanism of thermoregulation in rats and valuable information for future research on this topic, as well as for discussions on setting limit values for international exposure guidelines.

The exposure system used, which originally contained two lens antennas arranged side by side and was used to expose a human back, has been extensively characterised [11]. The incident power density (IPD) was determined in [11] by numerical simulations and measurements at a distance of about 50 cm from one of the antennas. Comparison of the results shows good agreement. However, the local variation of the IPD in an area positioned perpendicular to the antenna radiation direction and 50 cm from the antenna is very strong, which precludes exposure of the rats to a uniform field intensity. These field variations could also be responsible for the differences shown in the comparison with the referenced exposure simulations of human skin (see section 2 and [5]) exposed to a homogeneous plane wave. This variation (ripple) can be seen in the SAR distribution in the back of a rat model shown in [1]. The maxima of the local IPD and APD in the area of the exposed rat and the whole-body SAR, which are proportional to the antenna input power, were determined and represent the exposure levels in the evaluation of the experiments. However, it remains unclear whether the dorsal skin temperature measurements were carried out at a location within the 4 cm² averaging area of the local APD maximum, as a function of which the dorsal skin temperature change was analysed.

The changes in the physiological parameters in the rectum and tail are shown as a function of the whole-body SAR, as these areas are not directly exposed according to the authors. This is not entirely clear in the case of tail exposure: In the case of dorsal exposure of the rat, the tail, which is behind or next to the animal, should be exposed directly. This is also confirmed by the numerical SAR distribution shown in the publication, which clearly shows local SAR increases in the tail. In this context, the fact that the temperature increase in the tail at the end of the exposure is about twice as high as that in the back is also relevant. Therefore, it cannot be excluded that the observed temperature increases in the tail are not exclusively due to thermoregulation, but also to direct exposure-induced heating. This would make it difficult to determine the contribution of thermoregulatory mechanisms to the temperature increase in the tail.

The dependence of tail skin temperature on tail skin blood flow ("thermoregulatory model-2") appears to be relatively independent of exposure intensity. This relationship can therefore easily be represented by a single linear equation. In contrast, the relatively small coefficient of determination (R^2) of 'thermoregulatory model-1' indicates that exposure intensity affects the relationship between rectal temperature and tail skin blood flow. This potential influence has not been represented in the models. For the two exposure intensities, when considered separately, 'thermoregulatory model-1' would yield two regression lines with differing slopes. A simple linear regression, as used by the authors, could not represent such a relationship with sufficient accuracy.

A final assessment regarding the transferability of the shown results to humans is challenging. There are thermoregulatory functions that limit core body temperature in humans as thermal stress increases – for example, vasodilation or sweating [2]. The ratio of body mass to body surface area also has a significant influence on thermoregulation. However, the regulation of core body temperature in rats is largely (approximately 25 % [10]) achieved by heat dissipation to the environment via the tail. The “body mass to surface area” ratio also differs significantly between rats and humans. For these reasons, the applicability of the current results to existing human exposure guidelines, which take into account different thermoregulatory mechanisms, is severely limited.

Numerous experimental studies have investigated the effects of exposure of animals to electromagnetic fields. Depending on the intensity and duration of exposure, tissue heating and associated thermoregulatory mechanisms may be side effects leading to further changes in the endpoint of interest. Research such as the one considered here is therefore very helpful for a better understanding of potential effects.

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