

This **special issue** of the BERENIS newsletter summarizes the current knowledge on biological effects of millimeter waves (MMW) in the frequency range from 5.8 to 200 GHz, and it provides an assessment of the possible correlation between exposure and its effects and impact related to health. This is based on the identification and evaluation of relevant experimental animal and cell studies as well as studies with humans published in the period from the beginning of 2019 to August 2024. In May 2025, the FOEN published a comprehensive and more detailed report in German¹. This special issue contains a short version of the report.

Electromagnetic fields in the frequency range 5.8-200 GHz - Biological effects and consequences for health

Introduction and aims of this report

Millimeter waves (MMW, wavelengths in the millimeter range), hence, radiofrequency electromagnetic fields (RF-EMF) with frequencies above 6 GHz, are currently not used for mobile communications in Switzerland. With the increasing use of mobile communication and associated changes in the technologies, an implementation of MMW can be anticipated in the future to increase bandwidth. Knowledge about potential biological effects of RF-EMF in the new frequency bands for mobile communication is limited, and their possible health effects still remain largely unexplored.

Characteristics of millimeter waves

For frequencies above 6 GHz, absorption mainly occurs on the surface of the exposed cells, animals and humans. A suitable measure for the exposure of tissues is the incident power density (IPD; expressed in W/m^2)². Energy absorption (exposure intensity multiplied by duration per volume) can lead to a local or systemic increase in temperature, which triggers thermoregulation in the organism or causes metabolic and physiological changes. Thus, heating-related impact should also be taken into account, in addition to the putative athermal effects on biological functions and mechanisms. Such temperature increases can either be directly measured or estimated using computational modelling methods.

The **aim** of this special newsletter issue is to summarize the current knowledge about biological effects of MMW in the frequency range from 5.8 to 200 GHz and to assess the potential health impact of exposure. The health-related effects from many different experimental endpoints relate primarily to cancer, neurological and skin diseases, but also include other biological processes such as reproduction and fertility, developmental, cognitive and physiological aspects, as well as mechanisms involved in various physiological and pathological processes, such as oxidative stress and programmed cell death (apoptosis).

¹ www.bafu.admin.ch (Topic: Electrosmog and light > Publications and studies > Studies), and <https://www.aramis.admin.ch/Dokument.aspx?DocumentID=73167>

² In order to protect the population from excessive thermal effects, ICNIRP (2020) recommends reference values for whole-body exposure (under far-field conditions) of $10 \text{ W}/\text{m}^2$, averaged over 30 minutes. For local exposures (parts of the body), the reference value is depending on the frequency: i.e., between $40 \text{ W}/\text{m}^2$ (at 6 GHz) and $20 \text{ W}/\text{m}^2$ (at 300 GHz), averaged over 4 cm^2 and 6 minutes, as well as between $60 \text{ W}/\text{m}^2$ (at 30 GHz) and $40 \text{ W}/\text{m}^2$ (at 300 GHz), averaged over 1 cm^2 and 6 minutes.

Methods

Systematic selection of studies

This newsletter is based on a systematic review (see German report³), following standardised guidelines that take into account the selection of studies according to PECO criteria (population, exposure, comparisons and results), a systematic literature search in at least two databases and documentation in accordance with the PRISMA guidelines [1, 2]. This systematic review was conducted in accordance with scientific recommendations [3, 4] and considered experimental studies with cell cultures (*in vitro*), animals and volunteers (*in vivo*), and biological effects or mechanisms, and independently assessed these in a systematic evaluation. A synthesis of the study results was discussed with respect to relevance for health in the following categories:

1. carcinogenesis, neurodegenerative and other neurological diseases
2. diseases/effects on the highest exposed organs such as the skin and the eyes including thermal effects
3. cardiovascular and immunological diseases
4. fertility, reproduction and developmental processes
5. cellular vitality, proliferation and senescence
6. stress response and (cellular) homeostasis
7. genetic and epigenetic integrity (transcriptomics/proteomics)
8. studies with humans, besides characteristics on health, perception is included

Study assessment

Individual studies were assessed and evaluated for their quality by a Risk of Bias (RoB) analysis. This risk of bias analysis evaluates the studies in various domains, regarding sensitivity and risk of systemic errors, and it also provides a measure for the confidence in the results for the respective outcome. The final assessment was made using the GRADE approach (Grading of Recommendations Assessment, Development and Evaluation⁴), according to standardised guidelines in accordance with OHAT [3, 4] with minor adjustments for animal and cell studies.

Summary and assessment of MMW

For the period from early 2019 to August 2024, a total of 56 eligible studies, 29 animal/human studies and 28 cell studies, were identified and assessed. Most studies were conducted in the sub-MMW frequency range from 5.8 to 29 GHz (n=16 *in vivo*, n=10 *in vitro*), followed by studies with MMW in the frequency range 50-100 GHz (n=5 *in vivo*, n=13 *in vitro*), 101-200 GHz (n=3 *in vivo*, n=6 *in vitro*) and 30-49 GHz (n=3 *in vivo*, n=3 *in vitro*). In the risk of bias analysis, significant limitations with regard to exposure and dosimetry were assigned to 20 animal studies. Most of them (n=14) also have limitations in the temperature assessment, which is particularly relevant for some of the assessed outcome categories, for example: 4. fertility, reproduction and developmental processes. Similar limitations in different domains were also found in the assessment of the cell studies.

In the publication period under consideration, there is only one animal study on carcinogenesis related to MMW in the frequency range 5.8-29 GHz [5], which has various limitations in the study quality.

³ www.bafu.admin.ch (Topic: Electrosmog and light > Publications and studies > Studies), and <https://www.aramis.admin.ch/Dokument.aspx?DocumentID=73167>

⁴ <https://www.gradeworkinggroup.org>

Therefore, the available data does not allow any statements on potential cancer risks from MMW. Well-controlled studies on genotoxicity provide no evidence for carcinogenic effects from MMW within the regulatory limits in any of the frequency ranges [6-8]. These findings are generally consistent with recent studies in which various cell models were exposed to RF-EMF used for mobile communication in the pre-5G era [9-11]. Other relevant factors for carcinogenesis are effects on cell viability and cell proliferation. Yet, the current knowledge does not allow for any clear conclusions to be drawn about the impact of MMW exposure, as the confidence in the available evidence is generally low, and many different experimental approaches have been pursued.

Studies on potential health effects of MMW on the cardiovascular or the immune system provide contradictory results based on functional assays and biomarkers [12-16]. Only two *in vivo* studies with RF-EMF in the frequency range of 5.8-29 GHz, and outcomes related to cardiovascular diseases were identified [12, 17]. However, their findings regarding ECG and structural changes in the heart tissue were contradictory. Studies on cell cultures indicated a temporary increase in inflammation markers and an activation of the immune system after exposure in the frequency range 5.8-29 GHz [15, 16].

Effects of MMW on fertility, reproduction and developmental processes have been investigated in eight studies [18-25]. Taking into account the study quality, there is some evidence for adverse effects on reproduction and developmental processes by RF-EMF in the frequency range of 5.8-29 GHz, indicated by the multigenerational study in *C. elegans* with exposure at an early developmental stage and chronic exposure (SAR: 4 W/kg) [25]. Yet, no signs of oxidative stress were found with short-term strong exposure to 9.4 GHz RF-EMF [20].

An increase in cellular and/or oxidative stress could be responsible for these observations in the multigeneration study, as well as for the deficits in memory performance. This has also been described in studies with frequencies above 10 GHz [26, 27] and below 5.8 GHz (see review by Schuermann and Mevissen [28]). Effects and consequences of oxidative stress were addressed in a previously published BERENIS newsletter ([special issue January 2021](#)). Two older studies with limited quality provide indications for activity changes of enzymes that regulate the oxidative balance induced by MMW in different tissues [29, 30].

Deficits in memory performance and structural changes in various brain structures were reported in two studies with exposure in the frequency range 5.8-29 GHz [31, 32]. Studies in rodents and with primary neuronal cells indicated an inhibition of pain after exposure to higher frequencies (>60 GHz) [33-36]. Yet, the findings regarding the transmission of neuronal signals, i.e., synaptic transmission, are inconclusive [34, 35]. Global analyses of gene expression and proteins were performed to identify mechanisms and biomarkers for observed effects of MMW regarding neurological deficits, impacts on the immune system and therapeutical applications. Using this profiling approach, it was convincingly shown that exposure-dependent changes in gene expression by 60 GHz MMW (200 W/m²) were predominantly caused by thermal responses [37]. This highlights the importance of temperature control and dosimetry in the *in vitro* exposure model systems.

The studies on thermal effects, especially on skin and eye tissues, which are considered the most relevant targets of MMW exposure, are based on various model systems, i.e., rabbits, rats and mice, pigs, volunteers as well as different cell types [15, 27, 38-44]. The results reported are consistent with the conclusions of previously published reviews [45-47]. Most studies conducted with MMW have focussed on therapeutic applications, particularly for treatment of pain [13, 42, 48], whereas investigations on thermal thresholds of MMW exposure were scarce. A temperature increase of 0.9-1°C at the fingertip of human volunteers was reported as the threshold for pain caused by 28 GHz MMW in the range of 1260-3990 W/m² [42]. One study indicates an increase in the probability of damage to the rabbit eye at high incident power densities (1730, 2520, 3680 W/m²) [40]. For MMW in the frequency bands that may be used by future telecommunication technologies, the dosimetry and

experimental evidence is incomplete, and not very detailed with regard to temperature and thermal effects. In combination with the variety of experimental approaches used, it is not possible to draw firm conclusions about thermal effects of MMW on human skin and eye tissue.

Manifested by energy deposition and tissue heating, cell stress due to thermal action can cause protein mis-folding and an elevation in the expression of heat shock proteins. This effect has been investigated, and it was occasionally demonstrated in several studies at various MMW frequencies, IPDs, exposure durations and cell types [6, 7, 37, 49-56]. However, no changes of heat shock proteins were detected when ocular cells were exposed for 24 hours to RF-EMF (IPD: 10 W/m²) at frequencies of 5.8 GHz [7], 40 GHz [6] or 60 GHz [56]. Recent studies on hyperthermia focused on tumour therapy, in which intensive pulses with 58.4 GHz MMW caused heat shock reactions and permeability of the cell membrane [57-59]. However, effects that were attributed to increased permeability of the cell membrane were also observed after exposure to 60 GHz (IPD: 200 W/m²) [60]. There is a lack of well-conducted studies in mammals, and the confidence in the available experimental evidence is generally limited. Thus, the understanding of underlying mechanisms remains incomplete.

Conclusions

The studies on thermal effects of MMW show a temperature increase in laboratory animals, depending on the frequency and intensity. The available data do not allow any firm statements on possible threshold values, but there are indications that human volunteers can detect a local temperature increase of 1°C (in the range 1260-3990 W/m²). The evidence from studies on therapeutic applications suggests that especially pulsed RF-EMF exposure is an interesting method for cancer therapy, particularly for superficial skin tumours.

Some of the *in vivo* studies provide evidence for impaired learning behaviour as well as structural changes in the brain, which was associated with oxidative stress in some cases, as it has already been observed at lower frequencies (<5.8 GHz). At higher frequencies in the MMW range (>60 GHz), there are indications for altered neuronal activity, though these effects went in both directions depending on the study. Evidence from cell studies indicates an increased permeability of cell membranes after exposure to >60 GHz. The cause of this is still a matter of speculation, but it may be due to oxidative stress or effects on membrane channels, especially when pulsed MMW are used. Gene activity analyses were partially in line with the observed changes in neuronal and metabolic cell functions. So far, however, no distinct signalling pathway affected by the exposure or even a biomarker has been identified, which makes it difficult to draw conclusions with regard to human health.

Based on recent data mainly from *in vitro* studies on genotoxicity, effects of MMW on carcinogenesis are unlikely. However, only one animal study with considerable shortcomings in the study quality has been published, which investigated tumours of the subcutaneous tissue.

There are indications of impairment of reproduction after chronic exposure to 9.4 GHz MMW from a multi-generation study with nematodes, which is probably attributable to oxidative stress. However, studies on mammals are lacking.

Overall, a large number of the published studies have substantial limitations, particularly concerning exposure characterisation and dosimetry, and their results do not allow any conclusions regarding causality and health impact. Also, a reliable dose-response relationship can hardly be derived based on the available studies with frequent limitations. A statement on dose-dependency of effects cannot be made as there is a lack of such studies, and comparable experimental designs and endpoints have rarely been assessed.

BERENIS statement on the state of knowledge, ICNIRP guidelines and precautionary measures

- It remains difficult to draw conclusions on potential health effects of RF-EMF exposure in the MMW range after the systematic evaluation of the publications of the past five years. The current knowledge is still ambivalent and the confidence in the available evidence is limited. Many studies are afflicted with uncertainties and, especially if the exposure levels were above the regulatory limits, a contribution of thermal effects to the findings often cannot be ruled out.
- Even though no health effects have been demonstrated below the ICNIRP reference limits [61], some uncertainties remain. There is moderate evidence that RF-EMF exposure above 5.8 GHz affects learning performance, which may be associated with oxidative and cellular stress. However, no epidemiological studies (>5.8 GHz) are available, therefore, the relevance for human health cannot be assessed conclusively. As already stated in the [special newsletter issue from July 2020](#), BERENIS supports the consideration of the more precise guidelines for short-term and small-area exposures above 6 GHz by Swiss legislation before such frequencies will be implemented for mobile communications in the future.
- In view of these uncertainties, BERENIS continues to recommend consequent application of the precautionary principle. In Switzerland, the precautionary principle for emissions from stationary transmitters (e.g., mobile phone base stations and radio transmitters) is specified by the “installation limit value” in the Ordinance on Protection against Non-Ionising Radiation (NISV).
- With regard to the planned utilisation of the frequency range above 5.8 GHz in new communication technologies, we note that there are currently only few scientific studies with decent quality and reliable evidence. In particular, there is a lack of informative studies on mammals. It is therefore difficult to draw conclusions on potential health effects, especially for skin and eyes being the most exposed tissues. It is also not possible to make any firm statement on ecological consequences of MMW, as studies with small animals such as bees and other insects are mostly not available. To reduce the knowledge gaps, high-quality research should be initiated and promoted, to better assess the impact on health and the environment in the future.

References

1. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hrobjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P and Moher D (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, 372.
2. Page MJ, Moher D, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hrobjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P and McKenzie JE (2021). PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ*, 372.
3. NTP, National Toxicology Program. *Handbook for Conducting a Literature-based Health Assessment Using OHAT Approach for Systematic Review and Evidence Integration*. Office of Health Assessment and Translation. National Institute of Environmental Health Sciences., 2019.

4. NTP, National Toxicology Program. *OHAT Risk of Bias Rating Tool for Human and Animal Studies*. Office of Health Assessment and Translation. National Institute of Environmental Health Science. U.S. Department of Health and Human Service., 2019.
5. de Seze R, Poutriquet C, Gamez C, Maillot-Marechal E, Robidel F, Lecomte A and Fonta C (2020). Repeated exposure to nanosecond high power pulsed microwaves increases cancer incidence in rat. *PLoS One*, 15(4).
6. Koyama S, Narita E, Suzuki Y, Shiina T, Taki M, Shinohara N and Miyakoshi J (2019). Long-term exposure to a 40-GHz electromagnetic field does not affect genotoxicity or heat shock protein expression in HCE-T or SRA01/04 cells. *Journal of Radiation Research*, 60(4).
7. Miyakoshi J, Tonomura H, Koyama S, Narita E and Shinohara N (2019). Effects of Exposure to 5.8 GHz Electromagnetic Field on Micronucleus Formation, DNA Strand Breaks, and Heat Shock Protein Expressions in Cells Derived From Human Eye. *IEEE Transactions on Nanobioscience*, 18(2).
8. Lawler NB, Evans CW, Romanenko S, Chaudhari N, Fear M, Wood F, Smith NM, Wallace VP and Swaminathan Iyer K (2022). Millimeter waves alter DNA secondary structures and modulate the transcriptome in human fibroblasts. *Biomedical Optics Express*, 13(5).
9. Gläser K, Rohland M, Kleine-Ostmann T, Schrader T, Stopper H and Hintzsche H (2016). Effect of Radiofrequency Radiation on Human Hematopoietic Stem Cells. *Radiation Research*, 186(5).
10. Schuermann D, Ziemann C, Barekati Z, Capstick M, Oertel A, Focke F, Murbach M, Kuster N, Dasenbrock C and Schär P (2020). Assessment of Genotoxicity in Human Cells Exposed to Modulated Electromagnetic Fields of Wireless Communication Devices. *Genes*, 11(4).
11. Su LL, Wei XX, Xu ZP and Chen GD (2017). RF-EMF Exposure at 1800 MHz Did Not Elicit DNA Damage or Abnormal Cellular Behaviors in Different Neurogenic Cells. *Bioelectromagnetics*, 38(3).
12. Yao C, Wang H, Sun L, Ren K, Dong J, Wang H, Zhang J, Xu X, Yao B, Zhou H, Zhao L and Peng R (2022). The Biological Effects of Compound Microwave Exposure with 2.8 GHz and 9.3 GHz on Immune System: Transcriptomic and Proteomic Analysis. *Cells*, 11(23).
13. Minier L, Debouzy JC, Foerster M, Pierre V, Maindet C and Crouzier D (2023). Hypoalgesia and parasympathetic effects of millimeter waves on experimentally induced pain in healthy volunteers. *Electromagnetic Biology and Medicine*, 42(1).
14. Zhang Q, Shang S, Li X and Lu X (2024). Anti-Inflammatory and Immunomodulatory Effects of 0.1 Sub-Terahertz Irradiation in Collagen-Induced Arthritis Mice. *International Journal of Molecular Sciences*, 25(11).
15. Havas F, Cohen M, Krispin S and Attia-Vigneau J (2024). Protective Properties of Botanical Extracts against 5G Radiation-induced Damage to Human Skin, as Demonstrated in Preliminary Data from a Keratinocyte Cell Culture Model. *Frontiers in Bioscience (Landmark Ed)*, 29(1).
16. Yin Y, Xu X, Li D, Yao B, Wang H, Zhao L, Wang H, Dong J, Zhang J and Peng R (2023). Role of Cx43 in iPSC-CM Damage Induced by Microwave Radiation. *International Journal of Molecular Sciences*, 24(16).
17. Yin Y, Xu X, Gao Y, Wang J, Yao B, Zhao L, Wang H, Wang H, Dong J, Zhang J and Peng R (2021). Abnormal Expression of Connexin43 in Cardiac Injury Induced by S-Band and X-Band Microwave Exposure in Rats. *Journal of Immunology Research*, 2021.
18. Belyavskaya A, Loginov P, Mavlutova E and Nikolaev A (2020). Changes in Male Reproductive System Under Adverse Environmental Conditions. *Archiv EuroMedica*, 10(2).

19. Nik Abdull Halim NMH, Mohd Jamili AF, Che Dom N, Abd Rahman NH, Jamal Kareem Z and Dapari R (2024). The impact of radiofrequency exposure on *Aedes aegypti* (Diptera: Culicidae) development. *PLoS One*, 19(2).
20. Sun A, Li Z, Zhao X, Zhou H, Gao Y, Liu Q, Zhou S, Zhang C, Dong G and Wang C (2022). Pulsed High-Peak Power Microwaves at 9.4 GHz Do Not Affect Basic Endpoints in *Caenorhabditis elegans*. *Bioelectromagnetics*, 43(1).
21. Xue Y, Guo L, Lin J, Lai P, Rui G, Liu L, Huang R, Jing Y, Wang F and Ding G (2022). Effects of 5.8 GHz Microwaves on Testicular Structure and Function in Rats. *Biomed Research International*, 2022.
22. Ploskonos MV, Zulfalaeva DF, Kurbangalieva NR, Ripp SV, Neborak EV, Blagonravov ML, Syatkin SP, Sungrapova K and Hilal A (2022). Assessing the biological effects of microwave irradiation on human semen in vitro and determining the role of seminal plasma polyamines in this process. *Biomedical Reports*, 16(5).
23. Pecoraro R, Pavone SC, Scalisi EM, Ignoto S, Sica C, Indelicato S, Capparucci F, Iaria C, Salvaggio A, Sorbello G, Di Donato L and Brundo MV (2023). Multimarker Approach to Evaluate the Exposure to Electromagnetic Fields at 27 GHz on *Danio rerio* Larvae. *Journal of Marine Science and Engineering*, 11(4).
24. Pecoraro R, Pavone SC, Scalisi EM, Sica C, Ignoto S, Contino M, Salvaggio A, Marmara D, Sorbello G, Di Donato L and Brundo MV (2022). Biological Effects of Non-Ionizing Electromagnetic Fields at 27 GHz on Sperm Quality of *Mytilus galloprovincialis*. *Journal of Marine Science and Engineering*, 10(4).
25. Sun A, Zhao X, Li Z, Gao Y, Liu Q, Zhou H, Dong G and Wang C (2022). Effects of Long-Term and Multigeneration Exposure of *Caenorhabditis elegans* to 9.4 GHz Microwaves. *Bioelectromagnetics*, 43(5).
26. Kesari KK and Behari J (2010). Microwave Exposure Affecting Reproductive System in Male Rats. *Applied Biochemistry and Biotechnology*, 162(2).
27. Verma S, Keshri GK, Karmakar S, Mani KV, Chauhan S, Yadav A, Sharma M and Gupta A (2021). Effects of Microwave 10 GHz Radiation Exposure in the Skin of Rats: An Insight on Molecular Responses. *Radiation Research*, 196(4).
28. Schuermann D and Mevissen M (2021). Manmade Electromagnetic Fields and Oxidative Stress-Biological Effects and Consequences for Health. *International Journal of Molecular Sciences*, 22(7).
29. Kesari KK and Behari J (2009). Fifty-gigahertz microwave exposure effect of radiations on rat brain. *Applied Biochemistry and Biotechnology*, 158(1).
30. Kumar S, Kesari KK and Behari J (2010). Evaluation of genotoxic effects in male Wistar rats following microwave exposure. *Indian Journal of Experimental Biology*, 48(6).
31. Liu JJ, Zhang HY, Chen X, Zhang GB, Lin JK, Feng H and Chu WH (2022). 20-Hydroxyecdysone Improves Neuronal Differentiation of Adult Hippocampal Neural Stem Cells in High Power Microwave Radiation-Exposed Rats. *Biomedical and Environmental Sciences*, 35(6).
32. Wang H, Liu Y, Sun Y, Dong J, Xu X, Wang H, Zhao X, Zhang J, Yao B, Zhao L, Liu S and Peng R (2023). Changes in cognitive function, synaptic structure and protein expression after long-term exposure to 2.856 and 9.375 GHz microwaves. *Cell Communication and Signaling*, 21(1).
33. Ma S, Li Z, Gong S, Lu C, Li X and Li Y (2023). High Frequency Electromagnetic Radiation Stimulates Neuronal Growth and Hippocampal Synaptic Transmission. *Brain Sciences*, 13(4).
34. Zhao L, Yi R, Liu S, Chi Y, Tan S, Dong J, Wang H, Zhang J, Wang H, Xu X, Yao B, Wang B and Peng R (2023). Biological responses to terahertz radiation with different power density in primary hippocampal neurons. *PLoS One*, 18(1).

35. Sun L, Chen M, Wang H, Dong J, Zhao L and Peng R (2022). CaMKII δ Promotes Synaptic Plasticity under Terahertz Wave Radiation by Activation of the NF- κ B Pathway. *The Journal of Physical Chemistry Letters*, 13(25).
36. Tan SZ, Tan PC, Luo LQ, Chi YL, Yang ZL, Zhao XL, Zhao L, Dong J, Zhang J, Yao BW, Xu XP, Tian G, Chen JK, Wang H and Peng RY (2019). Exposure Effects of Terahertz Waves on Primary Neurons and Neuron-like Cells Under Nonthermal Conditions. *Biomedical and Environmental Sciences*, 32(10).
37. Martin C, Evrard B, Percevault F, Ryder K, Darde T, Lardenois A, Zhadobov M, Sauleau R, Chalmel F, Le Dr  an Y and Habauzit D (2024). Transcriptional landscape of human keratinocyte models exposed to 60-GHz millimeter-waves. *Toxicology In Vitro*, 97.
38. Emre M, Karamazi Y, Emre T, Avci   , Aydin C, Ebrahimi S and Pekmezekmek AB (2024). The effect of 6GHz radiofrequency electromagnetic radiation on rat pain perception. *Electromagnetic Biology and Medicine*, 43(1-2).
39. Ijima E, Kodera S, Hirata A, Hikage T, Matsumoto A, Ishitake T and Masuda H (2023). Excessive whole-body exposure to 28 GHz quasi-millimeter wave induces thermoregulation accompanied by a change in skin blood flow proportion in rats. *Frontiers in Public Health*, 11.
40. Kojima M, Suzuki Y, Tasaki T, Tatematsu Y, Mizuno M, Fukunari M and Sasaki H (2020). Clinical Course of High-Frequency Millimeter-Wave (162 GHz) Induced Ocular Injuries and Investigation of Damage Thresholds. *Journal of Infrared, Millimeter and Terahertz Waves*, 41(7).
41. Kojima M, Tsai CY, Suzuki Y, Sasaki K, Tasaki T, Taki M, Watanabe S and Sasaki H (2019). Ocular Response to Millimeter Wave Exposure Under Different Levels of Humidity. *Journal of Infrared, Millimeter and Terahertz Waves*, 40(5).
42. Yuasa A, Uehara S, Ushizawa K, Kodera S, Arai N, Hirata A and Otaka Y (2024). The thermal sensation threshold and its reliability induced by the exposure to 28 GHz millimeter-wave. *Frontiers in Neuroscience*, 18.
43. Furman O, Komoshvili K, Levitan J, Yahalom A, Marks H, Borodin D and Liberman-Aronov S (2020). The Lack of Toxic Effect of High-Power Short-Pulse 101 GHz Millimeter Waves on Healthy Mice. *Bioelectromagnetics*, 41(3).
44. Foroughimehr N, Clayton AHA and Yavari A (2024). Exploring Skin Interactions with 5G Millimeter-Wave through Fluorescence Lifetime Imaging Microscopy. *Electronics*, 13(9).
45. Wood A, Mate R and Karipidis K (2021). Meta-analysis of in vitro and in vivo studies of the biological effects of low-level millimetre waves. *Journal of Exposure Science and Environmental Epidemiology*, 31(4).
46. Simk   M and Mattsson MO (2019). 5G Wireless Communication and Health Effects-A Pragmatic Review Based on Available Studies Regarding 6 to 100 GHz. *International Journal of Environmental Research and Public Health*, 16(18).
47. Karipidis K, Mate R, Urban D, Tinker R and Wood A (2021). 5G mobile networks and health-a state-of-the-science review of the research into low-level RF fields above 6 GHz. *Journal of Exposure Science and Environmental Epidemiology*, 31(4).
48. Walters TJ, Blick DW, Johnson LR, Adair ER and Foster KR (2000). Heating and pain sensation produced in human skin by millimeter waves: Comparison to a simple thermal model. *Health Physics*, 78(3).
49. Zhadobov M, Nicolaz CN, Sauleau R, Desmots F, Thouroude D, Michel D and Le Dr  an Y (2009). Evaluation of the Potential Biological Effects of the 60-GHz Millimeter Waves Upon Human Cells. *Ieee Transactions on Antennas and Propagation*, 57(10).

50. Nicolaz CN, Zhadobov M, Desmots F, Ansart A, Sauleau R, Thouroude D, Michel D and Le Drean Y (2009). Study of narrow band millimeter-wave potential interactions with endoplasmic reticulum stress sensor genes. *Bioelectromagnetics*, 30(5).
51. Le Quement C, Nicolas Nicolaz C, Zhadobov M, Desmots F, Sauleau R, Aubry M, Michel D and Le Drean Y (2012). Whole-genome expression analysis in primary human keratinocyte cell cultures exposed to 60 GHz radiation. *Bioelectromagnetics*, 33(2).
52. Le Quement C, Nicolaz CN, Habauzit D, Zhadobov M, Sauleau R and Le Drean Y (2014). Impact of 60-GHz millimeter waves and corresponding heat effect on endoplasmic reticulum stress sensor gene expression. *Bioelectromagnetics*, 35(6).
53. Haas AJ, Le Page Y, Zhadobov M, Boriskin A, Sauleau R and Le Drean Y (2016). Impact of 60-GHz millimeter waves on stress and pain-related protein expression in differentiating neuron-like cells. *Bioelectromagnetics*, 37(7).
54. Zhadobov M, Sauleau R, Le Coq L, Debure L, Thouroude D, Michel D and Le Dréan Y (2007). Low-power millimeter wave radiations do not alter stress-sensitive gene expression of chaperone proteins. *Bioelectromagnetics*, 28(3).
55. Millenbaugh NJ, Roth C, Sypniewska R, Chan V, Eggers JS, Kiel JL, Blystone RV and Mason PA (2008). Gene expression changes in the skin of rats induced by prolonged 35 GHz millimeter-wave exposure. *Radiation Research*, 169(3).
56. Koyama S, Narita E, Shimizu Y, Suzuki Y, Shiina T, Taki M, Shinohara N and Miyakoshi J (2016). Effects of Long-Term Exposure to 60 GHz Millimeter-Wavelength Radiation on the Genotoxicity and Heat Shock Protein (Hsp) Expression of Cells Derived from Human Eye. *International Journal of Environmental Research and Public Health*, 13(8).
57. Orlacchio R, Le Page Y, Le Dréan Y, Le Guével R, Sauleau R, Alekseev S and Zhadobov M (2019). Millimeter-wave pulsed heating in vitro: cell mortality and heat shock response. *Scientific Reports*, 9(1).
58. Orlacchio R, Nikolayev D, Le Page Y, Le Drean Y and Zhadobov M (2022). Millimeter-Wave Heating In Vitro: Local Microscale Temperature Measurements Correlated to Heat Shock Cellular Response. *IEEE Transactions on Biomedical Engineering*, 69(2).
59. Orlacchio R, Page YL, Dréan YL and Zhadobov M (2023). Millimeter-Wave Pulsed Heating in Vitro: Effect of Pulse Duration. *IEEE Journal of Electromagnetics RF and Microwaves in Medicine and Biology*, 7(2).
60. Le Pogam P, Le Page Y, Habauzit D, Doué M, Zhadobov M, Sauleau R, Le Dréan Y and Rondeau D (2019). Untargeted metabolomics unveil alterations of biomembranes permeability in human HaCaT keratinocytes upon 60 GHz millimeter-wave exposure. *Scientific Reports*, 9(1).
61. ICNIRP (2020). ICNIRP Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz). *Health Physics*, 118.

Contact

Dr Stefan Dongus
BERENIS Secretariat
Swiss Tropical and Public Health Institute
Department of Epidemiology and Public Health
Environmental Exposures and Health Unit
Kreuzstrasse 2, CH-4123 Allschwil, Switzerland

Tel: +41 61 284 8111

Email: stefan.dongus@swisstph.ch

Additional information:

[BERENIS - Swiss expert group on electromagnetic fields and non-ionising radiation](#)

[BERENIS newsletter search tool](#)

[List of abbreviations \(pdf\)](#)