Health Matters

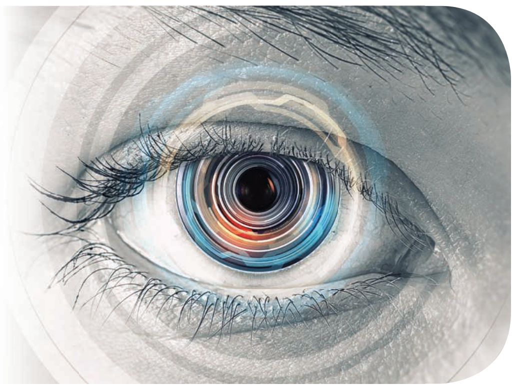
Health Safety Guidelines and 5G Wireless Radiation

■ James C. Lin

The rollout of 5G cellular communication technology is well underway worldwide. The advocates of 5G mobile technology hail it as a faster and more secure technology than its predecessor, 3G and 4G systems. The major enabling infrastructure uses millimeter-wave (mm-wave) and phased-array technology to achieve line-of-sight directivity, high data rates, and low latency. A central vulnerability or security threat is that it may allow spying on users. Nevertheless, this is a system architecture and technology or regulatory issue but not a biological effect or health safety matter.

5G Cellular Mobile Technology

5G cellular mobile technology is a telecommunication technology multilayered in frequency assignment and varied in operational scope and performance. It includes an extremely wide range of multiple RF bands. Its frequency coverage may be roughly separated into two ranges: sub-6-GHz bands and 24–60-GHz frequencies that reach well into the mm-wave region. The frequency ranges have often been further divided into low-, mid, and high-band 5G. Low-band 5G starts at roughly 400 MHz and uses existing or previous 3G or 4G frequencies or newly opened frequencies to operate; the latter, for example, may overlap with the existing 4G band. The 5G rollout began with midband, which includes popular frequencies between 3 and 4 GHz. However, primary 5G technological advances are associated with high-band 5G, which promises performance bandwidth as high as 20 GHz, and multiple-input, multiple-output strategies using 64–256 antennas at short distances and offering performances up to 10 times better than the current 4G networks.



From the perspective of frequency allocation, 5G encompasses an enormous range from 3 to 60 GHz and beyond, in one giant skip from 4G. Even with current technological advances, the demand and performance challenges clearly vary immensely from the low to high bands. The performance bandwidth of 20 GHz is obviously not viable or supportable at the low band. By design default or spectrum necessity, bandwidth performance will be accomplished only by leapfrogging to high-band 5G. The higher the 5G mm-wave bands, where the wider spectrum is accessible primarily at a shorter range, will lead to a massive proliferation of many microcells because existing cell towers are unsightly and too big for the urban settings where mm-wave phased arrays will be mostly deployed.

For health safety matters, it is not apparent whether the biological responses to high-band 5G radiations would be akin to earlier generations or low-band 5G radiations, given the distinctive characteristics of mm-wave

James C. Lin (lin@uic.edu) is with the University of Illinois at Chicago, Chicago, Illinois, 60607, USA.

Digital Object Identifier 10.1109/MMM.2021.3117307
Date of current version: 2 December 2021

and its interaction with the complex structure and composition of pertinent, superficial biological cells and tissues such as the cornea of the eye and nerve-rich human skin, the large, protective organ of the body.

Recent Updates of Health Safety Recommendations

The two most widely promulgated RF health safety guidelines or standards have recently published revisions of their respective 1998 and 2005 versions [1], [2]. The updated International Commission on Nonionizing Radiation Protection guidelines and IEEE standards appear to cater to industry wishes; they are strongly linked to thermal effects associated with measurable temperature elevations. Also, the updates seem to have been synchronized to accommodate the 5G rollout.

The World Health Organization's International Agency for Research on Cancer (IARC) classified exposure to RF radiation as a possible carcinogen to humans in 2011 [3], [4]. The IARC had evaluated then-available scientific studies and concluded that, although the evidence was incomplete and limited, especially regarding results from animal experiments, epidemiological studies of humans reporting increased risks for gliomas (a type of malignant brain cancer) and acoustic neuromas (or acoustic schwannomas—a nonmalignant tumor of Schwann-cell-sheathed auditory nerves on the side of the brain) among heavy or long-term users of mobile telephones are sufficiently strong to support a classification of possibly carcinogenic in humans for exposure to RF radiation from mobile phones.

It is noteworthy that the coveted animal experiments have indeed been published in 2018. Specifically, the National Toxicology Program (NTP) of the U.S. National Institute of Environmental Health Science (NIEHS) reported observations of two types of cancers in laboratory rats exposed, lifelong, to the RF radiation used for 2G and 3G mobile telephone operations [5]. It was the largest health effect study ever undertaken by the NIEHS/NTP and concluded, among other observations, that there was statistically significant and clear evidence that RF radiation had led to the development of malignant schwannoma (a rare form of tumor) in the heart of male rats whose body temperature did not exceed 1 °C. Further, there was evidence of the same schwannoma risk among female rats. The NTP also noted that there were unusual patterns of cardiomyopathy, or damage to heart tissue, in both RF-exposed male and female rats when compared with concurrent control animals. In addition, based on statistical significance, the pathology findings showed indications of some evidence of RF-dependent carcinogenic activity in the brain of male rats, specifically glioma. However, the findings for female rats were deemed as providing only equivocal evidence for malignant gliomas when compared with concurrent controls.

Moreover, shortly after the NTP report, the Cesare Maltoni Cancer Research Center at the Ramazzini Institute in Bologna, Italy, published the results from its comprehensive study on carcinogenicity in rats exposed (either lifelong or prenatal until death) to 3G, 1,800-MHz, RF radiation [6]. The study involved the whole-body exposure of male and female rats under plane-wave-equivalent or far-zone exposure conditions. The authors estimated that the whole-body specific absorption rates were 0.001, 0.03, and 0.1 W/kg during exposures of 19 h/day for approximately two years. A statistically significant increase in the rate of schwannomas in the heart of male rats was detected for whole-body 0.1 W/kg RF exposure. It is important to note that the NTP and Ramazzini RF exposure studies presented similar findings in heart schwannomas and brain gliomas. Thus, two relatively well-conducted RF exposure studies employing the same strain of rats showed consistent results in significantly increased cancer risks.

Although recognizing that the two aforementioned studies used large numbers of animals, best-laboratory practices, and animals exposed for the entirety of their lives, recent safety updates preferred to quibble with alleged "chance differences" among treatment conditions and the fact that the measured animal body-core temperature changes reached 1 °C. Ironically, in doing so, it may have overlooked the absurdity of inferring a 1 °C body-core temperature rise as being carcinogenic. Furthermore, it totally ignored the implications of RF agents, or had chosen to sidestep them through such pretexts as the evidence or findings do not provide a credible indication of adverse effects caused by chronic RF exposures.

Human Eye and Skin Tissues

For high-band 5G, the distinctive characteristics of mm-wave and its interaction with the complex function and structure of relevant biological tissues associated with the cornea of the eye and the large, protective organ of the skin are of special concern.

The human skin tissue is roughly 2–3 mm in thickness. It is not homogeneous but consists of several major layers of stratum corneum, epidermis, dermis, and the deeper, subcutaneous hypodermis. It has a total mass of approximately 3 kg and covers nearly the entire body surface (roughly 1.85 m^2). It is further differentiated according to its location on the body. It can vary in thickness depending on what part of the body it is covering. On the back, it may be greater than 2-mm thick, and on the eyelids, it can be less than 0.35-mm thick. Also, the skin is an important sensory organ endowed with nerve endings that are sensitive to touch, pain, and warmth. Anatomically, it is the largest organ of the human body. Its various constituent cells and tissues help to keep microbes out, hold body fluids in, and prevent dehydration.

The power-reflection coefficients of the skin for mm-wave decrease from 60 to 20% as frequency increases, while the power-transmission coefficient increases from 50 to 65%. The penetration depth in which the power deposition is reduced by an exponential factor (e^{-2}) for a planar mm-wave decreases from 1.2 to 0.4 mm for skin, while the induced energy deposition increases with mm-wave frequency [7]. However, at the highest frequencies, energy deposition in the deeper regions in the skin is lower because of the reduced penetration depth at these frequencies [8].

Biological Interactions With Mm-Waves

The studies on mm-wave interactions aimed both toward biological effects and medical applications began nearly 50 years ago, most notably in Russia or the former Soviet Union. A comprehensive review of research on the biological effects of mm-wave from some of the earliest studies showed that at incident power densities of 100 W/m^2 or less, mm-wave can affect cell growth and proliferation, enzyme activity, genetic status, function of excitable membranes, peripheral receptors, and other biological systems [9]. However, a common concern has been the lack of clarity in reported experimental protocols, rigor in statistical analysis, inadequate in situ dosimetry, and the absence of sham-exposure and temperature controls as well as paucity of reported details.

A recent paper provided an updated summary of the results published from Russia since 1997, including a few related studies from elsewhere [10]. The review focused on experimental findings of mm-wave effects at subcellular and cellular levels, including cell proliferation and gene expression. It also contained effects on excitable tissues and immune systems, and responses from the eyes and skin. It concluded that available data showed incident mm-wave power densities below 100 W/m^2 do not produce any harmful effect on eyes, but exposures at higher levels may result in adverse effects that are dependent on the frequency and duration of exposure. Likewise, studies have shown the absence of genotoxic effects in skin cells or changes in gene expression for low-power exposures without significant temperature elevations. However, the results on proliferative effects for cells of different types have been contentious.

Furthermore, although some recent studies did not show nonthermal changes in electrical activity and the structure of excitable cells, the rate of mm-wave power deposition was noted to play a significant role in eliciting the electrical-potential response of nerve cells. Mm-waves have been reported to produce systemic effects on humans and animals that involve hypoalgesia and endogenous opioids and can affect immune and nervous systems' behavior around 100 W/m^2. There have been suggestions that systemic responses are initiated by the stimulation of free nerve endings in the skin, followed by the modulation of central neural activity.

Recently, several reviews have been published that were based mostly on data from papers written in English [11]–[13]. A 2019 review [11] included 45 in vivo studies conducted using laboratory animals and other biological preparations, and 53 in vitro studies involving primary cells and cultured cell lines. This review was based on published papers through the end of 2018 using 6–100 GHz as the RF source frequency. However, because fewer studies were reported at 30 GHz or below and at frequencies higher than 90 GHz, the review mainly covered published studies conducted in the mm-wave frequency range from approximately 30 to 65 GHz.

This industry-supported review noted that aside from the wide frequency ranges, the studies were diverse, both in subject matters and end points investigated. The biological effects were observed to occur both in vivo and in vitro for the different biological endpoints studied. Indeed, the percentage of positive responses at nonthermal levels in most of the frequency groups was as high as 70%. (Higher mm-wave intensities, up to 200 W/m^2, did not seem to cause any greater responses.) For example, in the 53 in vitro studies involving primary cells (n=24) or cell lines (n= 9), approximately 70% of the primary cell studies and 40% of the cell-line investigations showed effects that were related to mm-wave exposure. However, the protocol applied for control of biological target or culture medium temperature during mm-wave exposure was uncertain in a large fraction of these studies.

An overview of the published scientific literature on the possible effects of mm-waves on skin and skin cells in 2020 counted a total of 99 experimental studies [12]. Many of these were focused on the thermal stress and pathophysiology associated with exposure to high power densities.

More recently, a review from the Australian government included 107 experimental studies (91 in vitro, 15 in vivo, and 1 human) that investigated various biological effects of mm-waves, including genotoxicity, cell proliferation, gene expression, cell signaling, membrane function, and other effects [13]. It asserted that the review of experimental studies provided no confirmed evidence that low-level mm-waves are associated with biological effects relevant to human health. It suggested that many of the studies reporting effects came from the same research groups and that the results have not been independently reproduced. Most of the studies employed low-quality methods of exposure assessment and control, so the possibility of experimental artifact cannot be excluded. Furthermore, many of the effects reported may have been related to heating from high power deposition, so the assertion of a low-level effect is questionable in many of the studies.

To date, there has not been a single reported epidemiological study that investigated mm-waves and their potential health effects.

Thus, although there are roughly 100 published laboratory investigations of all types, and the reported biological responses are inconsistent in their association between biological effects and mm-wave exposure. Indeed, the types of reported laboratory investigations are small, limited, and

TABLE 1. The thermal-effect-based guidelines or standards for short-term (6 or 30 min) exposure.

Spectrum Range	Key ΔT Parameter	ΔT (°C)	Average Mass/Area	Average Time (min)	Health-Effect Level	Safety Factor*	General Public Level	Safety Factor*	Worker Level**
100 kHz–300 GHz	Body core	1	Whole-body average	30	4 W/kg	50	0.08 W/kg	10	0.4 W/kg
100 kHz–6 GHz	Local head and torso	2	10 g	6	20 W/kg	10	2 W/kg	2	20 W/kg
	Local limbs	2	10 g	6	40 W/kg	10	4 W/kg	2	40 W/kg
>6 GHz–300 GHz	Local head and torso	5	4 cm^2	6	200 W/m^2	10	20 W/m^2 (in 1 cm^2)	2	100 W/m^2
30 GHz–300 GHz	Local limbs	5	2 cm^2	6	400 W/m^2	10	40 W/m^2 (in 1 cm^2)	2	200 W/m^2

*Reduction factor; **workers' occupational or controlled exposure.

diverse, considering the wide, 5G, mm-wave frequency domain. The jury on biological effects or health impacts is still out on 5G mm-waves. Moreover, there is a lack of ongoing, controlled laboratory investigations. To help improve the situation, new laboratory investigations should provide experimental designs with statistical validity that support methods, procedures, and protocols amenable to independent replication and must include quantitative exposure, dosimetry, and temperature determination and control.

Anomalies in Recently Updated Safety Recommendations

The recently updated safety guidelines and standards make recommendations to purportedly protect against established, adverse health effects in humans resulting from exposure to electromagnetic fields in the frequency range between 6 and 300 GHz. In fact, these are recommendations for short-term exposures of 6 to 30 min, based on limiting whole-body temperatures from rising above 1 °C or tissue temperatures to 5 °C (Table 1) [1], [2].

If the entities responsible for safety recommendations believe what appears to be their position concerning experimental results from rats from the NIEHS/NTP that a whole-body temperature rise of 1 °C is carcinogenic, then the safety factors of 50 adopted for the public or 10 for workers would be marginal for their stated purpose and practically meaningless from the perspective of "safety" protection (more so above 6 GHz).

It is noteworthy that the average power density thresholds under controlled laboratory conditions for microwave auditory effect in human subjects with normal hearing for 10–32 μs pulses are approximately 14 kW/m^2 in the near field of 1,250–3,000 MHz sources [8]. In other words, the 14-kW/m^2 per pulse-peak power density generates a barely audible sound level of 0 dB. Generating sound at 60 dB, the audible level for normal conversation, requires a 1,000-fold higher power density per pulse. Generating a tissue-injuring level of sound at 120 dB would take another 1,000-fold increase in required peak power density, or 14 GW/m^2 per pulse. Such high-power, microwave-pulse-generated, acoustic pressure waves can be initiated in the brain and then reverberated inside the head to potentially, if not surely, cause serious injury of white and gray brain matters, along with other neural elements [6]. Yet the corresponding, theoretical temperature elevation would be roughly 1 °C, which is considered safe by current protection guidelines. Of course, the clinical implications are uncertain at present and would demand future study for clarification.

As shown in Table 1, for mm-waves, the referenced local-tissue-temperature rise in the head, torso, and limbs of humans is 5 °C. This level of temperature rise would bring the tissue temperature from a normal value of 37 °C to a hyperthermic 42 °C. A 42 °C tissue temperature is known to be cytotoxic, with exponential cell-killing capacities. It is used as the basis for clinical cancer therapy in hyperthermia treatment for cancer protocols [14]–[16]. The recently updated safety recommendations provide a reduction factor of 10 for the public's safety and a reduction factor of two in the case of workers. In this situation, the efficacy of these updated safety recommendations is borderline, and the updated recommendations are meaningless from the perspective of safety protection.

In summary, the safety recommendation updates were based primarily on limiting the tissue-heating potentials of RF radiation to elevate body temperatures. There are significant anomalies in the recently updated safety recommendations. Moreover, aside from the aforementioned anomalies, the existing scientific data are too limited—especially at mm-wavelengths—to make a reliable assessment or conclusion with any certainty. Some of the updated safety recommendations are marginal, questionable, and lack scientific justification from the perspective of safety protection.

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for a unifying theoretical framework to biological problems. The successful collaboration resulted in papers in *Science* and *Nature* in the late 1990s and, more recently, in a book [4] on biological scaling laws.

> As West notes [4], Metabolic rate is the fundamental rate of biology, setting the pace of life for almost everything an organism does. . . . . The basal metabolic rate of the average human being is only about 90 watts, corresponding to a typical incandescent light bulb and equivalent to the approximately 2,000 food [kilo]calories you eat every day.

How does this metabolic rate change with the size of an organism? The Swiss physiologist Max Kleiber had already observed in 1932 that "the metabolic rate scales as a power law whose exponent is very close to the number ¾" [4]. For example, an animal twice the size of another one requires only 75% more food and energy each day, rather than 100% more. This scaling law was found to be valid across all taxonomic groups and all sizes from mice to elephants. West and his colleagues developed a quantitative framework to explain this scaling law "rooted in the universal mathematical, dynamical, and organizational properties of the multiple networks that distribute energy, materials, and information to local microscopic sites that permeate organisms" [4]. Amazingly, according to West, the same scaling law applies even to the growth of cities and companies!

As sophisticated computer simulations and laboratory data have become available, the IEEE RF safe exposure standard C95.1 has also continued to evolve since the days of Schwan's heuristic analysis based on the base metabolic rate. More research, especially in the millimeter-wave frequency bands now being used for 5G, is still needed. The D.C. Circuit Court noted in a recent ruling that although "it takes no position in the scientific debate over the health and environmental effects of RF radiation" [5], the Federal Communications Commission needs "to explain why its current guidelines [dating to 1996] adequately protect against the harmful consequences of exposure to radio frequency (RF) radiation unrelated to cancer" [5].

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