James C. Lin
University of Illinois at Chicago
851 South Morgan Street, M/C 154
Chicago, IL 60607-7053 USA
E-mail: lin@uic.edu

Safety Guidelines and 5G Communication RF Radiation

James C. Lin

University of Illinois at Chicago
851 S. Morgan St. (M/C 154)
Chicago, IL 60607 USA
E-mail: lin@uic.edu

The health and safety implications of fifth-generation (5G) cellular-communication technology have been under scrutiny while the rollout is well underway worldwide. Advocates of 5G mobile technology hail 5G 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 technologies 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 or health safety matter.

1. 5G Cellular Mobile Technology

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

From the perspective of frequency allocation, 5G encompasses an enormous range, from 3 GHz 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 obviously is not viable or supportable at low-band. By design default or spectrum necessity, the bandwidth performance will only be accomplished by leapfrogging to the high-band 5G. The higher 5G mm-wave bands where the wider spectrum is accessible primarily at shorter range will lead to massive proliferation of many micro-cells, because existing cell towers are unsightly and too big for the urban settings where mm-wave phased-arrays will mostly be deployed. For health safety matters, it is not obvious 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 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.

2. Recent Updates of Safety Recommendations

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

The World Health Organization's (WHO's) International Agency for Research on Cancer (IARC) classified exposure to RF radiation as a possible carcinogen to humans in 2011. The IARC had evaluated then-available scientific studies and concluded that, while evidence was incomplete and limited – especially regarding results from animal experiments – epidemiological studies of humans reported that increased risks for gliomas (a type of malignant brain cancer) and acoustic neuromas (or acoustic schwannomas, a non-malignant 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 [3, 4].

It is noteworthy that the coveted animal experiments were indeed published in 2018. Specifically, the National Toxicology Program (NTP) of the US National Institute of Environmental Health Science (NIEHS) reported observations of two types of cancers in laboratory rats exposed, life long, to RF radiation used for 2G and 3G mobile telephone operations [5]. It was the largest health-effect study ever undertaken by NIEHS/NTP. Among other observations, it concluded that there was statistically significant and clear evidence that the 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 also evidence for the same schwannoma risk among female rats. 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 for 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.

Furthermore, 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, 1800 MHz RF radiation [6]. The study involved whole-body exposure of male and female rats under plane-wave equivalent or far-zone exposure conditions. The authors estimated that the whole-body SARs were 0.001 W/kg, 0.03 W/kg, 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 hearts 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. Two relatively well-conducted RF exposure studies employing the same strain of rats thus showed consistent results in significantly increased cancer risks.

While recognizing that the two afore-mentioned studies used large numbers of animals, best laboratory practice, and animals exposed for the entirety of their lives, the recent updates preferred to quibble with alleged "chance differences" between treatment conditions and the fact that the measured animal body core temperature changes reached 1°C. 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 have chosen to sidestep them through such pretexts as that the evidence or findings did not provide credible indication of adverse effects caused by chronic RF exposures.

3. High Band 5G mm-Waves

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 about 2 mm in thickness. It is not homogeneous, but consists of three major layers of stratum corneum, epidermis, and dermis. It has a total mass of about 3 kg, and covers nearly the entire body surface (about 1.85 m^2). It is differentiated according to its location on the body, and it can vary in thickness depending on what part of the body it is covering. On the back, it may be greater than 2.0 mm thick, and on the eyelids, it can be less than 0.35 mm thick. The skin is also 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 decreases from 60% to 20% as frequency increases, while the power transmission coefficient increases from 50% to 65%. The penetration depth, where the power deposition is reduced by an exponential factor (e^{-2}) of a planar mm-wavefront, decreases from 1.2 mm to 0.4 mm for skin, and the induced energy deposition increases with mm-wave frequency [7]. However, at the highest frequencies the energy deposition in the deeper regions inside the skin is lower, because of the reduced penetration depth at these frequencies [8].

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 biological effects of mm-wave from some the earlier studies showed that at incident power densities of $100\ \mathrm{W/m^2}$ 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, absence of sham-exposure and temperature controls, as well as paucity of reported details.

A recent paper provided an updated summary of 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 on the eyes and skin. It concluded that available data showed incident mm-wave power densities below $100\ \mathrm{W/m^2}$ does not produce any harmful effect on eyes, but exposures at higher levels may result in adverse effects that dependent on the frequency and duration of exposure. Likewise, studies have shown 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 are contentious.

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

Recently, several reviews were published 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. The review was based on published papers through the end of 2018 using 6 GHz to 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 about 30 GHz to 65 GHz.

This industry-supported review noted that aside from the wide frequency ranges, the studies were diverse in both subject matter and end points investigated. Biological effects were observed to occur both in-vivo and in-vitro for different biological endpoints studied. Indeed, the percentage of positive responses at non-thermal levels in most frequency groups was as high as 70%. (Higher mm-wave intensities, up to $200\ \mathrm{W/m^2}$, did not seem to cause any greater responses.) For example, in the 53 in-vitro studies involving primary cells ($n = 24$) or cell lines ($n = 29$), 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 total published scientific literature on the possible effects of mm-waves on skin and skin cells in 2020 counted only 99 experimental studies [12]. Many of these were focused on 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 one 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 were associated with biological effects relevant to human health. It suggested that many of the studies reporting effects came from the same research groups and 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 could not 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 was no reported epidemiological study that investigated mm waves and their potential health effects.

While there are about 100 published laboratory

Table 1 Thermal Effect Based Guidelines or Standards for Short-Term (6 or 30 min) Exposure

Spectrum Range	Key ΔT Parameter	ΔT	Average Mass/Area	Average Time	Health Effect Level	Safety Factor*	General Public Level	Safety Factor*	Worker** Level
100 kHz-300 GHz	Body Core	1 °C	WBA***	30 min	4 W/kg	50	0.08 W/kg	10	0.4 W/kg
100 kHz – 6 GHz	Local Head-Torso	2 °C	10 g	6 min	20 W/kg	10	2 W/kg	2	20 W/kg
	Local Limbs	2 °C	10 g	6 min	40 W/kg	10	4 W/kg	2	40 W/kg
> 6 GHz – 300 GHz	Local Head-Torso	5 °C	4 cm^2	6 min	200 W/m^2	10	20 W/m^2 (in 4 cm^2)	2	100 W/m^2
30 GHz – 300 GHz	Local Limbs	5 °C	2 cm^2	6 min	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; *** WBA - Whole Body Average

investigations of all types, the reported biological responses were thus inconsistency in the association between biological effects and mm-wave exposure. Indeed, the types of reported laboratory investigations were small, limited, and diverse, considering the wide 5G mm-wave frequency domain. The jury on biological effect or health impact 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.

4. Anomalies in Recently Updated Safety Recommendations

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

If the responsible entities believe what appears to be their position concerning experimental results from rats from NIEHS/NTP that a whole-body temperature rise of 1°C is carcinogenic, then the safety factors of 10 for the public or 50 for workers would be marginal 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 μs to 32 μs pulses are about 14 kW/m^2 in the near field of 1250 MHz to 3000 MHz [8]. In other words, the 14 kW/m^2 per pulse peak power density generates a barely audible sound level of 0 dB. To generate sound at 60 dB, or the audible level for normal conversation, requires 1000-fold higher power density per pulse. To generate a tissue-injuring level of sound at 120 dB would take another 1000-fold increase in required peak power density, or 14 GW/m^2 per pulse. Such a high-power microwave pulse-generated acoustic pressure wave can be initiated in the brain and then reverberate inside the head to potentially, if not surely, cause serious injury of white and grey brain matters along with other neural elements [6]. Yet the corresponding theoretical temperature elevation would be about 1°C, which would be "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 reference 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 "safety factor" of two in the case of workers. 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. However, aside from the above-mentioned anomalies, the existing scientific data is too limited, especially at mm wavelengths, for any 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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