

MOBILE-PHONE RADIOFREQUENCY EXPOSURE: UNDERSTANDING SPECIFIC ABSORPTION RATE (SAR), HEALTH EVIDENCE AND PRACTICAL RISK REDUCTION

Tapan Kumar Mahato*

Ranchi College of Pharmacy, Namkum, Ranchi, Jharkhand.

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*Corresponding Author: Tapan Kumar Mahato

Ranchi College of Pharmacy, Namkum, Ranchi, Jharkhand.

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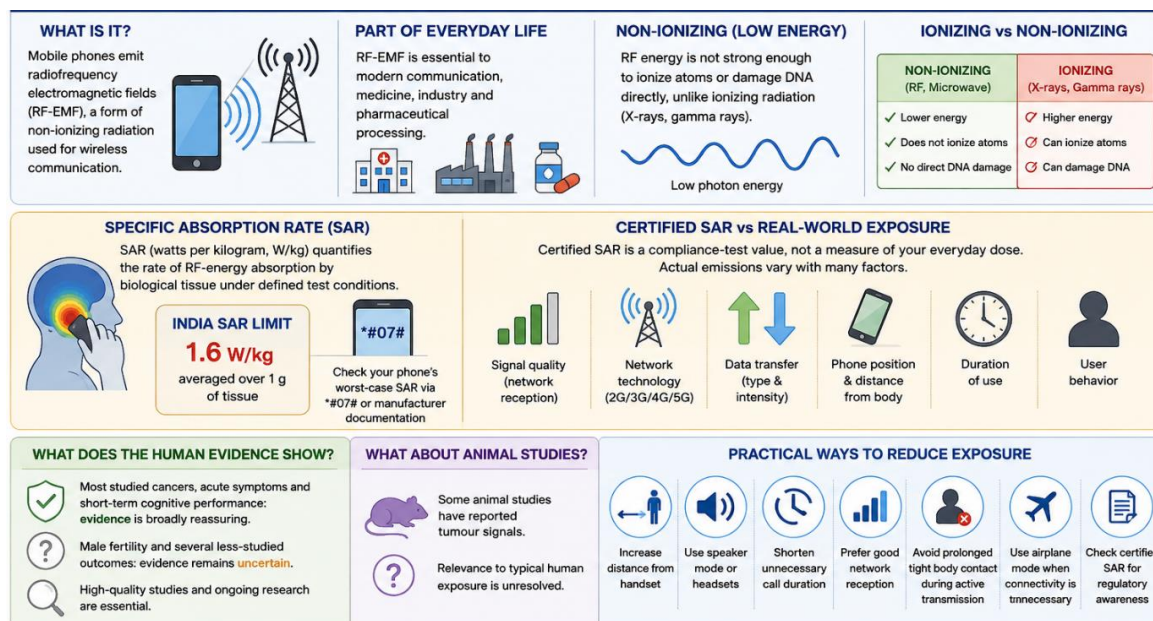
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ABSTRACT

Radiation is integral to modern medicine, communication, industry, and pharmaceutical processing, yet public discussion often fails to distinguish ionizing radiation from non-ionizing electromagnetic fields. Mobile phones emit radiofrequency electromagnetic fields (RF-EMF), a form of non-ionizing radiation used for wireless communication. This review article critically reviews radiation types and beneficial applications, with emphasis on mobile-phone RF exposure, specific absorption rate (SAR), health implications, and practical exposure-reduction strategies. SAR, expressed as watts per kilogram (W/kg), quantifies the rate of RF-energy absorption by biological tissue under defined conditions. In India, mobile handsets are required to comply with a localized SAR limit of 1.6 W/kg averaged over 1 g of tissue, and the handset's worst-case SAR can generally be accessed through the *#07# regulatory display or manufacturer documentation. Certified SAR is a compliance-test value rather than a direct measure of a user's everyday dose, because actual emissions vary with signal quality, network technology, data transfer, phone position, distance, and duration of use. Recent systematic reviews of human evidence are broadly reassuring for the most studied cancers, acute symptoms, and short-term cognitive performance, whereas evidence for male fertility and several less-studied outcomes remains uncertain. Selected animal studies have reported tumour signals, but their relevance to typical human exposure is unresolved. Sensible precautionary measures, especially increasing distance, using speaker mode or headsets, shortening unnecessary calls, and avoiding prolonged calls under weak signal conditions, can reduce exposure without compromising the benefits of mobile communication. Continued research using real-world dosimetry and modern 4G/5G exposure patterns remains warranted.

KEYWORDS: Radiofrequency electromagnetic fields; Mobile-phone radiation; Specific absorption rate; SAR; Non-ionizing radiation; Microwave radiation; 5G; Human health.



1. INTRODUCTION

1.1 Electromagnetic radiation: Radiation is energy transmitted through space or matter as electromagnetic waves or energetic particles. The term is often associated only with radioactivity, X-rays or nuclear hazards, although the electromagnetic spectrum extends from extremely low-frequency fields and radio waves through infrared, visible and ultraviolet radiation to X-rays and gamma rays. Biological effects depend on frequency, photon energy, intensity, duration, distance, exposure geometry and tissue interaction; therefore, health interpretation requires a clear distinction between ionizing and non-ionizing radiation (ICNIRP, 2020).

Ionizing radiation has sufficient energy to remove electrons from atoms or molecules. X-rays, gamma rays and energetic particle radiation can damage biologically important molecules at sufficient doses and increase the probability of adverse tissue effects. Nevertheless, controlled ionizing radiation is indispensable in diagnostic imaging, nuclear medicine, radiotherapy and sterilization; its benefits and risks depend on dose, purpose and exposure control. Non-ionizing radiation includes static and extremely low-frequency fields, radiofrequency electromagnetic fields (RF-EMF), microwaves, infrared radiation and visible light. These forms do not possess sufficient photon energy to directly ionize atoms. RF-EMF supports broadcasting, radar, satellite communication, Wi-Fi, Bluetooth and mobile telecommunications; at sufficiently high intensities, absorbed RF energy can heat tissue, which is the established interaction underlying present RF exposure restrictions (ICNIRP, 2020; Elwood & Karipidis, 2026).

Microwave radiation also illustrates the controlled beneficial use of non-ionizing energy. In pharmaceutical science, microwave-assisted dielectric heating has been applied to synthesis, extraction, drying and crystallization and, under suitable conditions, may shorten processing time and reduce energy use (Mahato et al., 2022; Mahato, 2026). This example emphasizes that biological risk depends on exposure conditions and interaction mechanisms rather than on the word “radiation” itself. Mobile phones attract particular public interest because of their widespread use and close proximity to the body. Smartphones may communicate through 2G, 3G, 4G/LTE and 5G cellular networks as well as Wi-Fi, Bluetooth and other short-range systems. During cellular transmission, the handset sends RF energy toward a base station, and use close to the head or trunk can produce greater localized exposure than distant environmental RF sources.

The expression “mobile radiation” can be misleading because smartphones do not emit radioactive or ionizing radiation. Mobile-phone RF photons cannot directly ionize biological molecules. At sufficiently high exposure, RF energy can produce tissue heating, and current exposure standards are designed to keep exposure below levels associated with harmful thermal effects (ICNIRP, 2020). Concern about possible long-term effects intensified after IARC classified RF electromagnetic fields in 2011 as Group 2B, “possibly carcinogenic to humans,” based principally on limited evidence for glioma and acoustic neuroma (IARC, 2013). This classification concerns the strength of hazard evidence and does not quantify risk at typical consumer exposure levels; it should therefore not be interpreted as proof that mobile phones cause cancer.

Since the IARC assessment, the evidence base has expanded substantially. Recent systematic reviews are broadly reassuring for the most studied cancers, acute self-reported symptoms and short-term cognitive performance, whereas evidence for male fertility and several less-studied outcomes remains uncertain. In-vitro genotoxicity findings are largely negative overall, while selected animal studies have reported tumour signals whose relevance to typical human smartphone exposure remains unresolved (Karipidis et al., 2024, 2025; Bosch-Capblanch et al., 2024; Pophof et al., 2024; Kenny et al., 2024; Romeo et al., 2024; Mevissen et al., 2025). These outcomes are examined in detail in Section 8. A central concept in mobile-phone exposure is the specific absorption rate (SAR), expressed in W/kg, which quantifies RF-energy absorption per unit mass of tissue under defined conditions. In India, handsets must comply with a localized SAR limit of 1.6 W/kg averaged over 1 g of tissue, with the worst-case value accessible through the regulatory display. However, certified SAR is a compliance value rather than a measure of an individual’s continuous everyday dose.

Actual handset emissions vary with signal quality, network configuration, voice or data activity, frequency band, phone position and duration of use. Real-world monitoring confirms that calls and cellular uploads can increase uplink emission and that poorer reception may require higher handset transmit power (Fontaine et al., 2026). Consequently, a lower certified maximum SAR does not necessarily imply lower exposure in every real-life situation. This focused review therefore clarifies radiation classification, mobile-phone RF emissions, SAR and its limitations, current evidence on major health outcomes, and practical exposure-reduction measures. Its central objective is to support proportionate risk communication by distinguishing established effects from unresolved questions and by avoiding both unnecessary alarm and unjustified certainty.

1.2 Literature search strategy: This article was prepared as a focused narrative review of current evidence concerning radiation, mobile-phone radiofrequency electromagnetic fields (RF-EMF), specific absorption rate (SAR), potential health effects, and practical exposure-reduction measures. Relevant literature was identified through targeted searches of PubMed, Google Scholar, and reference lists of key publications, together with authoritative documents issued by the World Health Organization (WHO), International Agency for Research on Cancer (IARC), International Commission on Non-Ionizing Radiation Protection (ICNIRP), and relevant Indian telecommunication regulatory authorities. Search terms included combinations of “radiofrequency electromagnetic fields,” “mobile phone radiation,” “smartphone RF exposure,” “specific absorption rate,” “SAR,” “5G,” “cancer,” “cognition,” “headache,” “electromagnetic hypersensitivity,” “male fertility,” “genotoxicity,” “animal cancer studies,” and “RF exposure reduction.” Priority was given to recent systematic reviews, meta-analyses, controlled human studies, major epidemiological investigations, experimental animal studies, real-world dosimetry research, and internationally

recognized exposure guidelines. Earlier landmark publications were included where necessary to provide historical or regulatory context. Evidence from different study designs was interpreted according to its methodological strength, with greater emphasis placed on systematic reviews and well-controlled studies than on isolated observational findings or case reports. As this was a focused narrative review rather than a formal systematic review, no PRISMA-based study-selection or quantitative meta-analysis was undertaken.

2. Radiation: Meaning and classification

2.1 Electromagnetic radiation: Electromagnetic radiation consists of oscillating electric and magnetic fields capable of transferring energy through space.

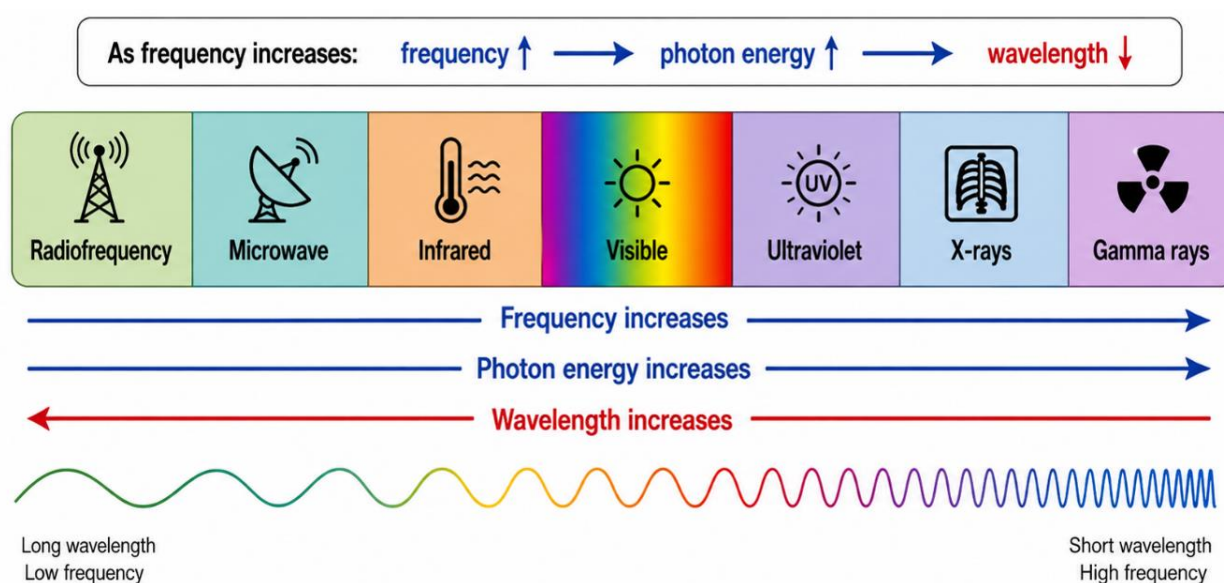


Figure 1: Arrangement of electromagnetic spectrum. The electromagnetic spectrum is arranged according to wave length, frequency and photon energy. Source: Author's original graphical synthesis based on ICNIRP (2020) and IARC (2013).

The crucial dividing concept for health interpretation is not simply frequency, but whether individual photons possess enough energy to ionize biological molecules.

2.2 Ionizing radiation: Ionizing radiation can remove electrons from atoms or molecules. Major examples include alpha particles, beta particles, x-rays, gamma rays, neutrons. Depending on dose and tissue exposure, ionizing radiation can produce molecular ionization, oxidative reactions, DNA strand damage, tissue injury and increased cancer risk. Its controlled applications, however, include diagnostic radiology, computed tomography, nuclear medicine, radiotherapy, sterilization, industrial radiography and scientific research.

2.3 Non-ionizing radiation: Non-ionizing radiation lacks sufficient photon energy to directly ionize atoms. Important forms include static electromagnetic fields, extremely low-frequency fields, radiofrequency radiation, microwave radiation, infrared radiation and visible light. Mobile phones operate principally in the radiofrequency/microwave portion of the non-ionizing spectrum (ICNIRP, 2020).

Table 1: Major radiation types, common applications and principal biological considerations. Source: Author's synthesis based on ICNIRP (2020), IARC (2013), Mahato et al. (2022), and Mahato (2026).

Radiation type/region	Ionizing status	Important applications	Principal biological consideration
Static/ELF fields	Non-ionizing	Electrical equipment, power systems, MRI static fields	Induced electrical effects at sufficiently high exposure
Radiofrequency	Non-ionizing	Mobile communication, radio, television, Wi-Fi, Bluetooth	Tissue heating at sufficiently high intensities (ICNIRP, 2020)
Microwaves	Non-ionizing	Telecommunications, radar, domestic heating, pharmaceutical synthesis and extraction	Dielectric heating; controlled energy absorption (Mahato et al., 2022; Mahato, 2026)
Infrared	Non-ionizing	Heating, thermal imaging, sensing	Primarily thermal effects
Visible light	Non-ionizing	Vision, illumination, microscopy, optical technology	Photochemical/thermal effects at high intensity
Ultraviolet	Primarily non-ionizing optical radiation, but highly energetic	Sunlight, phototherapy, disinfection	Photochemical damage to skin and eyes
X-rays	Ionizing	Radiography, CT, fluoroscopy	Molecular ionization and DNA damage at sufficient dose
Gamma rays	Ionizing	Radiotherapy, nuclear medicine, sterilization	Highly penetrating ionizing radiation
Alpha/beta/neutron radiation	Ionizing particle radiation	Nuclear processes, research, selected therapies	Ionization; effects depend strongly on particle type and dose

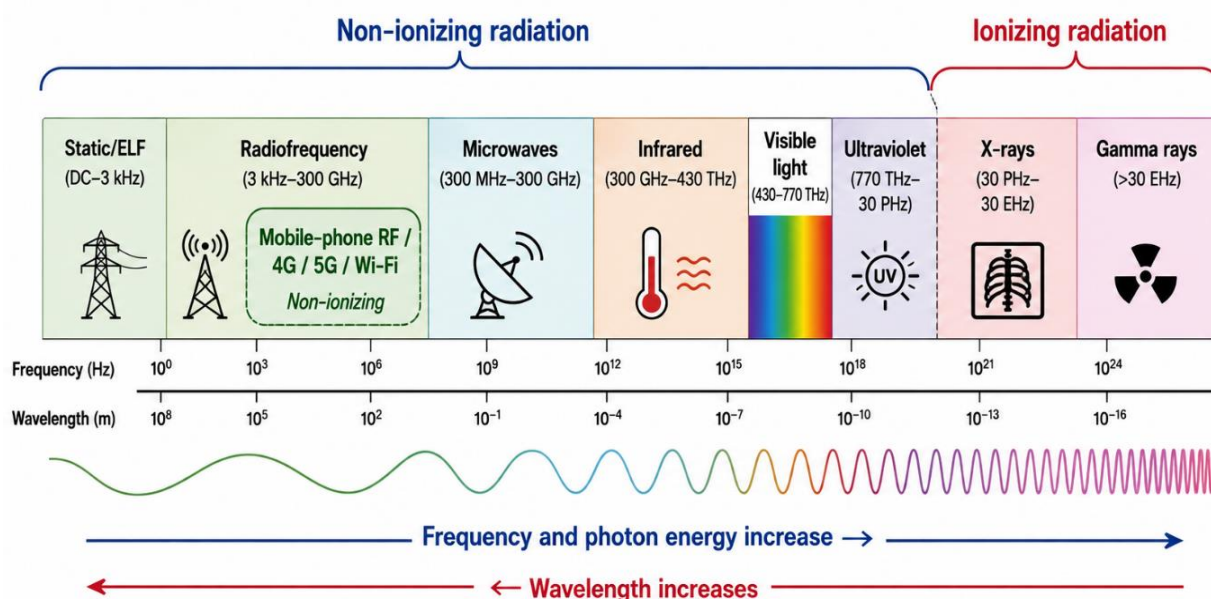


Figure 2: Simplified electromagnetic spectrum showing the position of mobile-phone radiofrequency electromagnetic fields. Mobile-phone RF, including 4G and 5G frequencies, lies within the non-ionizing portion of the electromagnetic spectrum and is fundamentally different from ionizing radiation such as X-rays and gamma rays. Source: Author's original graphical synthesis based on ICNIRP (2020) and IARC (2013); not reproduced or adapted from any previously published figure.

3. Beneficial uses of radiation: Radiation is central to many technologies that improve health, communication and industrial productivity.

3.1 Medical applications: Ionizing radiation is used in diagnostic X-ray imaging, computed tomography, fluoroscopy, nuclear medicine, cancer radiotherapy, sterilization of medical products. Non-ionizing electromagnetic energy is used in magnetic resonance imaging systems, medical diathermy, laser therapy, phototherapy, infrared thermography, wireless physiological monitoring.

3.2 Pharmaceutical applications of microwave radiation: In pharmaceutical processing, microwave energy can heat polar and ionic materials through dipolar polarization and ionic conduction, enabling rapid volumetric heating. Applications include synthesis, extraction, drying and crystallization, with potential reductions in processing time and energy use under suitable conditions (Mahato et al., 2022; Mahato, 2026). This concise example illustrates that the effects of radiation depend on exposure characteristics and interaction mechanisms rather than the term itself.

4. What is mobile-phone radiation?: Mobile phones generate RF electromagnetic fields while exchanging information through cellular and short-range wireless systems. A handset may be used against the ear, carried close to the body or placed at a distance; because localized exposure decreases markedly with separation, phone position is an important determinant of exposure.

4.1 Mobile radiation is non-ionizing: Mobile-phone RF should not be confused with radioactive contamination, X-rays or gamma rays. RF photons cannot directly ionize biological molecules; the established safety-relevant interaction at sufficiently high exposure is tissue heating (ICNIRP, 2020).

4.2 Why does a phone's RF output change?: A handset does not normally transmit continuously at its certified maximum power. Output varies with signal strength, network technology, frequency band, call or upload activity, antenna configuration and power-control algorithms. Real-world data show greater uplink emissions during calls and data uploads and potentially higher transmit power under poorer reception (Fontaine et al., 2026). In simplified terms: poor reception may increase handset transmit power, whereas good reception, greater distance and shorter transmission time generally reduce localized exposure.

5. Specific absorption rate (SAR)

5.1 Definition: The specific absorption rate (SAR) describes the rate at which RF electromagnetic energy is absorbed per unit mass of tissue. Its unit is W/kg = watts per kilogram. Conceptually, $SAR = \text{Absorbed RF power} / \text{Mass of tissue}$. For conductive biological tissue, SAR may also be described as

$$SAR = \sigma E^2 / \rho$$

Where, σ = electrical conductivity of the tissue, E = root-mean-square electric-field strength within tissue, ρ = tissue mass density. SAR is therefore a measure of absorbed electromagnetic energy, not simply transmitted phone power.

5.2 Localized and whole-body SAR: Whole-body averaged SAR represents average energy absorption across the entire body whereas localized SAR represents RF absorption within a specified small tissue mass and is particularly important for devices used near the head or trunk. Because mobile phones are used very close to the body, localized SAR is central to handset compliance testing.

5.3 SAR limit for mobile phones in India: Indian telecommunications requirements prescribe:

Maximum handset SAR = 1.6 W/kg averaged over 1 g of human tissue.

The handset should display the single worst-case SAR value through the MMI code: *#07#. This value represents compliance-testing information, not the user's instantaneous everyday exposure.

Table 2: Selected SAR exposure restrictions and their interpretation. Important: A value averaged over 1 g cannot be directly compared numerically with a value averaged over 10 g as though the measurement procedures were identical. Source: ICNIRP (2020) and Telecommunication engineering centre requirements.

System	Local head/trunk restriction	Averaging mass	Interpretation
Indian handset requirement	1.6 W/kg	1 g tissue	Mobile handsets marketed under applicable Indian requirements must comply with this limit
ICNIRP general-public local SAR restriction up to 6 GHz	2 W/kg	10 g tissue	International health-based restriction for local head/torso exposure
ICNIRP whole-body average	0.08 W/kg	Whole body	Whole-body exposure restriction rather than handset head SAR

6. Why knowing the SAR value is useful

6.1 Verification of regulatory compliance: SAR primarily demonstrates that RF absorption remains within the applicable restriction under standardized test conditions.

6.2 Consumer awareness: SAR confirms that handset RF absorption is measurable and subject to regulatory limits and compliance testing.

6.3 Device comparison: SAR values can be compared only when the same standard, averaging mass and exposure configuration are used; a lower listed maximum SAR does not guarantee lower exposure in every real-life condition.

6.4 What SAR does not tell the consumer: Published SAR is not a person's instantaneous or lifetime RF dose, does not indicate ionizing radiation, and is not a direct predictor of disease or real-world device ranking.

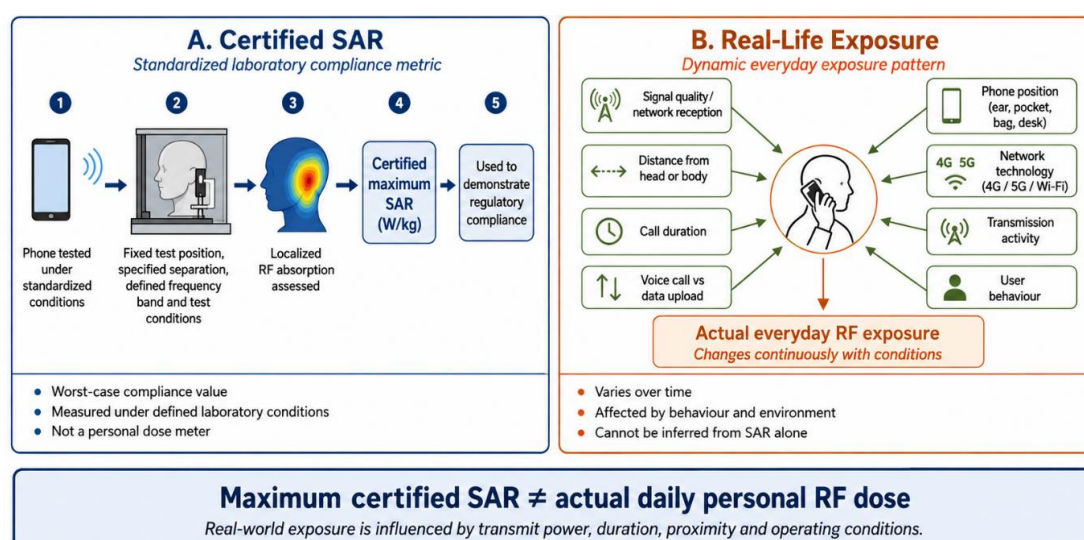


Figure 3: Relationship between certified SAR and real-life exposure. Certified SAR is a standardized laboratory compliance metric determined under defined test conditions, whereas actual everyday RF exposure varies dynamically according to signal quality, transmission activity, phone position, distance from the body, duration of use, network technology and user behaviour. Source: Author's original conceptual synthesis based on ICNIRP (2020), Telecommunication Engineering Centre (TEC) handset requirements, and Fontaine et al. (2026).

7. How can a consumer find the SAR of a mobile phone?

7.1 *#07# method: For handsets complying with applicable Indian requirements dial *#07#. The phone should display regulatory/SAR information, including the worst-case SAR value as applicable.

7.2 Manufacturer information: SAR may also be available from the manufacturer's official regulatory information, product safety information, user manuals, packaging, online technical documentation.

7.3 Phone settings: Depending on brand and operating system, information may appear under pathways such as:
Settings → About Phone → Legal/Regulatory Information → RF Exposure/SAR
The exact path varies between models.

7.4 Can a mobile application measure SAR?: An ordinary mobile-phone application should **not** be considered capable of directly measuring tissue SAR accurately. Professional SAR measurement requires specialized laboratory systems involving standardized phone positioning, calibrated electromagnetic probes, tissue-equivalent materials or validated numerical models, controlled transmission conditions, defined frequency bands, validated dosimetric protocols. Some applications merely retrieve the manufacturer's stored regulatory SAR value. That is not the same as measuring the user's instantaneous biological SAR.

8. Current evidence on mobile-phone RF-EMF and human health

8.1 Established thermal effects: At sufficiently high intensity, RF energy can increase tissue temperature. This thermal interaction is well established and forms a major scientific basis for RF exposure guidelines (ICNIRP, 2020). At compliant mobile-phone exposure levels, restrictions are designed to prevent harmful temperature increases with safety margins.

8.2 Mobile phones and cancer: Cancer has been one of the most extensively studied possible consequences of mobile-phone RF exposure. IARC classified RF electromagnetic fields as Group 2B, possibly carcinogenic to humans (IARC, 2013). That historical classification reflected the evidence available at the time. More recent evidence is more extensive. Karipidis et al. (2024) reviewed human observational studies of the most researched cancer outcomes and found that mobile-phone use did not appear to increase the risk of glioma, meningioma, acoustic neuroma, pituitary tumours, salivary-gland tumours and several related head-tumour outcomes. The review did not find convincing risk increases with greater call numbers, call duration or longer time since first use. Karipidis et al. (2025) subsequently assessed less-studied cancer outcomes and likewise found no clear evidence of increased risk for several cancer types, although certainty was lower because fewer suitable studies existed. Current human epidemiological evidence is broadly reassuring for the most extensively investigated cancers, but long-term monitoring remains scientifically justified as lifetime exposure patterns and technologies evolve.

8.3 Headache, fatigue, sleep disturbance and electromagnetic hypersensitivity: Some people report headache, dizziness, fatigue, tinnitus, sleep disturbance, concentration problems, skin sensations or general ill health in association with wireless devices. Bosch-Capblanch et al. (2024) systematically evaluated controlled experimental evidence and found that acute RF-EMF exposure below regulatory limits did not convincingly cause self-reported symptoms. Participants generally could not distinguish active RF exposure from sham exposure more accurately than

chance. Rösli et al. (2024) similarly found no consistent causal evidence linking RF exposure with tinnitus, migraine, headaches, sleep disturbance or composite non-specific symptoms, although the certainty of some evidence was low.

8.4 How should case reports of “Electromagnetic hypersensitivity” be interpreted?: Case reports can be valuable for generating hypotheses but cannot independently establish causality. For example, Hardell and Koppel (2023) described a worker reporting headache, tinnitus, dizziness, fatigue, insomnia and other symptoms attributed to electromagnetic-field exposure near telecommunications sources. Such case observations deserve respectful clinical assessment but cannot determine whether RF exposure caused the symptoms because they lack randomized exposure, adequate control groups, blinding, control for expectation/nocebo effects, rigorous assessment of alternative medical explanations. When such case reports are considered alongside blinded experimental studies, the stronger evidence presently does not demonstrate that acute RF exposure below regulatory limits reliably produces such symptoms (Bosch-Capblanch et al., 2024). This example illustrates why case evidence and systematic controlled evidence should not be assigned equal causal weight.

8.5 Cognitive effects: Concerns have been raised regarding memory, learning, attention, concentration, reaction time, executive function. Pophof et al. (2024) included 76 human experimental studies involving thousands of participants. Meta-analyses did not identify statistically significant deterioration in cognitive performance following short-term RF exposure. Benke et al. (2024), examining observational studies of longer-term exposure, reported little to no association across several cognitive domains, although evidence certainty was generally low because relatively few suitable studies existed. Current findings therefore do not support a consistent substantial cognitive deficit from ordinary RF-EMF exposure.

8.6 Reproductive health and male fertility: Potential reproductive effects have attracted attention because many users carry smartphones close to the reproductive organs. Possible outcomes investigated include sperm concentration, sperm count, sperm motility, sperm morphology, reproductive hormones, fertility. Kenny et al. (2024) concluded that current human observational evidence concerning male fertility is predominantly very low certainty. Major limitations include self-reported mobile-phone exposure, difficulty determining actual RF dose, differences in phone-carrying behaviour, lifestyle confounding, small samples, heterogeneous semen-analysis procedures. Therefore, harm has not been established, but uncertainty remains.

8.7 Genotoxicity and DNA damage: RF radiation does not have sufficient photon energy to directly ionize DNA. Nevertheless, researchers have examined possible indirect effects such as oxidative stress, DNA strand breaks, micronucleus formation, chromosomal alterations. Romeo et al. (2024) reviewed 159 publications containing a large number of in-vitro experimental comparisons. Approximately 80% of experiments reported no statistically significant effect across most endpoints. The review concluded that the overall evidence did not convincingly support increased RF-induced genotoxicity in mammalian cells.

8.8 Animal cancer studies: Animal studies permit controlled long-duration exposure not feasible in humans. Mevissen et al. (2025) reviewed RF-EMF cancer studies in experimental animals and reported increased incidence of selected tumours in some male-rat chronic bioassays, including glial-cell-derived neoplasms and cardiac schwannoma-related findings. A corrigendum published in 2026 subsequently corrected several inconsistencies in the original systematic review, primarily related to data extraction, the distinction between numbers of studies and experiments, animal counts,

classification of tumour types, and benchmark-dose calculations. In particular, astrocytomas were reclassified within glial-cell-derived neoplasms, and the benchmark-dose analysis for heart schwannomas in one study was recalculated using the intended 1% response level. Importantly, the authors stated that these corrections did not produce a significant change in the overall outcomes, interpretation or conclusions of the systematic review (Mevisen et al., 2026). Thus, the reported animal tumour signals remain scientifically relevant for hazard identification, although their quantitative relevance to typical human mobile-phone exposure remains uncertain.

These findings are scientifically important but should not be directly converted into predictions of human mobile-phone cancer risk because whole-body animal exposure differs from localized handset exposure, experimental SAR levels can differ, lifetime exposure schedules differ, species and tissue biology differ, appropriate dose metrics for cross-species extrapolation remain debated. Thus, animal signals support continued research but do not override the generally reassuring contemporary human epidemiological evidence (Elwood & Karipidis, 2026).

8.9 Smartphone interaction with pacemakers and defibrillators: A separate smartphone-related health issue concerns electromagnetic or magnetic interference with implanted cardiac electronic devices. This is important because it can mistakenly be described as an effect of “mobile radiation.” Nadeem et al. (2021) showed that the strong magnets incorporated into MagSafe-equipped smartphones could trigger magnet-sensitive functions in certain pacemakers and implantable cardioverter-defibrillators when the handset was placed directly over the device. This effect is primarily related to static magnetic-field interaction, not RF-induced tissue injury. Patients with implanted cardiac devices should therefore follow device-manufacturer and medical recommendations regarding phone separation.

Table 3: Hierarchy of recent evidence concerning mobile-phone/RF-EMF health outcomes. Source: Author’s synthesis from the cited studies. The evidence hierarchy shown here is intended to indicate the relative ability of different study designs to support causal interpretation and should not be interpreted as a formal GRADE certainty assessment.

Health outcome	Representative evidence	Evidence type / interpretive weight	Current interpretation
Tissue heating	ICNIRP (2020)	Established biophysical effect and guideline evidence — Highest confidence for established mechanism	RF energy can produce tissue heating at sufficiently high exposure. Prevention of adverse thermal effects forms a principal basis of current RF exposure restrictions.
Acute self-reported symptoms	Bosch-Capblanch et al. (2024)	Systematic review of controlled human experimental studies — High relevance for short-term causal effects	RF-EMF exposure below regulatory limits did not convincingly cause acute self-reported symptoms, and participants generally could not distinguish active from sham exposure better than chance.
Short-term cognitive performance	Pophof et al. (2024)	Systematic review and meta-analysis of controlled human experimental studies — High relevance for short-term causal effects	Meta-analyses did not demonstrate significant deterioration in cognitive performance following short-term RF-EMF exposure.
Glioma, meningioma, acoustic neuroma and other extensively	Karipidis et al. (2024)	Systematic review of human observational epidemiological studies — Strong population-level evidence, but observational	No convincing increased risk was identified for the most extensively studied cancers, including with greater call duration, number of

studied tumours			calls or longer time since first use.
Less-studied cancers	Karipidis et al. (2025)	Systematic review of human observational studies — Moderate interpretive weight because evidence is less extensive	No clear association was identified for several less-studied cancer outcomes, although certainty is lower because fewer suitable studies are available.
Headache, tinnitus, migraine and sleep-related symptoms	Röösli et al. (2024)	Systematic review and meta-analysis of human observational studies — Moderate evidence for association; limited for causality	No consistent association was demonstrated, although uncertainty remains for some outcomes because of limitations in the available evidence.
Longer-term cognition	Benke et al. (2024)	Systematic review and meta-analysis of human observational studies — Moderate-to-low certainty for long-term causal inference	Little to no association was observed across several cognitive domains, but the evidence base remains relatively small and frequently of low certainty.
Male fertility	Kenny et al. (2024)	Systematic review and dose-response meta-analysis of human observational studies — Low/very-low certainty because of exposure and confounding limitations	Current human evidence does not establish a causal adverse effect on male fertility; however, important uncertainty remains.
In-vitro genotoxicity	Romeo et al. (2024)	Systematic review of laboratory cell studies — Mechanistic/supportive evidence, indirect for human disease risk	The overall evidence did not convincingly support increased RF-EMF-induced genotoxicity in mammalian cells.
Animal tumour outcomes	Mevissen et al. (2025; corrigendum 2026)	Systematic review of experimental animal studies — Important hazard evidence but indirect for quantitative human risk	Selected tumour signals were reported in some animal bioassays. Their relevance to ordinary human mobile-phone exposure remains uncertain because exposure patterns, dosimetry and species biology differ.
Self-attributed electromagnetic hypersensitivity — individual reports	Hardell & Koppel (2023)	Case report/case study — Very low evidential weight for establishing causality	Individual symptom reports can generate hypotheses but cannot establish that RF exposure caused the reported symptoms. Controlled human evidence should receive greater causal weight.
Interference with implanted cardiac electronic devices	Nadeem et al. (2021)	Experimental/device-interaction evidence — Direct evidence for close-proximity magnetic interference	Magnets incorporated into some smartphones can interfere with certain pacemakers or implantable cardioverter-defibrillators at very close proximity. This is primarily a magnetic-device interaction rather than RF-induced tissue injury.

9. Why the maximum SAR value does not equal everyday exposure: Consider two compliant smartphones with maximum SAR values of 0.70 and 1.20 W/kg. The lower value does not guarantee lower daily exposure. If the lower-SAR phone is held against the ear for a long call under weak reception while the higher-SAR phone is used briefly on speaker mode under strong reception, the actual exposure pattern may be very different. Conceptually, real-world exposure is influenced by transmit power, duration, proximity and operating conditions; therefore, maximum certified SAR is not equivalent to actual daily RF dose.

10. 4G, 5G and emerging wireless technologies: The introduction of 5G generated renewed concern because the technology can use additional frequency bands and advanced antenna systems. However, statements such as “5G has a higher frequency, therefore it must be more dangerous” are scientifically incomplete. Biological exposure depends on

frequency, transmitted power, distance, duration, penetration depth, antenna configuration, duty cycle, absorbed energy. ICNIRP (2020) guidelines cover RF electromagnetic fields from 100 kHz to 300 GHz, encompassing mobile communication technologies, Wi-Fi, Bluetooth and 5G. For localized RF exposure, the appropriate dosimetric quantity depends on frequency. Under the ICNIRP (2020) guidelines, specific absorption rate (SAR) is used as the principal internal dosimetric quantity for localized exposure from 100 kHz to 6 GHz. For frequencies above 6 GHz and up to 300 GHz, RF energy is absorbed increasingly within superficial tissues; consequently, localized absorbed power density, expressed in W/m^2 , replaces localized SAR as the relevant basic restriction. For the general public, ICNIRP specifies a local head/torso SAR restriction of 2 W/kg averaged over 10 g of contiguous tissue from 100 kHz to 6 GHz, whereas above 6 GHz the general-public local absorbed-power-density restriction is 20 W/m^2 averaged over a 4-cm² body surface area and 6 minutes. These frequency-dependent metrics reflect differences in tissue penetration and energy deposition and should not be interpreted as evidence that higher-frequency 5G signals are inherently more hazardous.

11. Practical measures to reduce mobile-phone RF exposure: The following measures reduce RF exposure on basic physical and dosimetric principles. They should be presented as optional prudent exposure-reduction strategies, not as evidence that ordinary compliant mobile phones have been established to cause disease.

11.1 Increase distance: Increasing the distance between an actively transmitting mobile phone and the head or body is one of the simplest and most effective ways to reduce localized RF exposure. When practical, users may employ speakerphone mode or a wired headset, thereby keeping the primary cellular transmitter away from the head. Bluetooth headsets can also substantially increase the distance between the mobile handset and the head and generally operate at much lower transmitting power than cellular handsets; however, Bluetooth devices are themselves low-power RF transmitters. Therefore, where the specific objective is to minimize RF exposure close to the head, speakerphone mode or a wired headset provides the most straightforward exposure-reduction approach.

11.2 Avoid unnecessarily long calls: Where practical, shorten prolonged calls, divide long conversations, use speaker mode, use text-based communication when appropriate. Reducing transmission duration reduces cumulative exposure.

11.3 Prefer good signal conditions: Avoid very long calls, when practical, in locations where the phone has difficulty maintaining a signal, such as lifts/elevators, deep basements, poorly covered indoor rooms, remote areas with very weak reception, rapidly moving vehicles with unstable connections. Fontaine et al. (2026) provide contemporary evidence that poor reception can be associated with greater smartphone uplink emission. Connection to a stable Wi-Fi network may reduce cellular uplink emissions during some smartphone activities; however, because Wi-Fi itself uses radiofrequency electromagnetic fields, this should be interpreted as a change in the pattern and source of RF exposure rather than as a guaranteed reduction in total RF exposure (Fontaine et al., 2026).

11.4 Avoid unnecessary continuous body contact: When continuous contact is not required, place the phone on a desk, use a handbag/backpack rather than tight body contact, follow the manufacturer's minimum-separation instructions where specified.

11.5 Use airplane mode when wireless communication is not needed: Airplane mode may be useful when the device is being used only as an alarm, for reading downloaded material or for playing offline media, and wireless connectivity is not required.

11.6 Keep the phone away from the head during sleep when convenient: There is no established evidence that a compliant phone beside the bed causes disease through RF exposure. Nevertheless, if wireless connectivity is unnecessary overnight, exposure can readily be reduced by increasing distance, using airplane mode, switching off unnecessary wireless functions. Such habits may also reduce screen-related sleep disturbance and notifications.

11.7 Do not rely on unverified “Anti-radiation” shields: Commercial stickers, chips and shielding accessories should not automatically be assumed to reduce SAR. Poorly designed shielding can interfere with antenna performance, potentially causing the handset to alter its transmission power. Increasing distance and reducing unnecessary transmission are more scientifically straightforward methods.

11.8 Children and adolescents: Current evidence does not establish that compliant mobile-phone RF exposure causes disease specifically in children. Nevertheless, children may accumulate decades of device use. Reasonable habits include speaker mode for prolonged calls, avoiding unnecessary lengthy calls, keeping actively transmitting devices away from the body when practical, encouraging healthy screen-use and sleep habits.

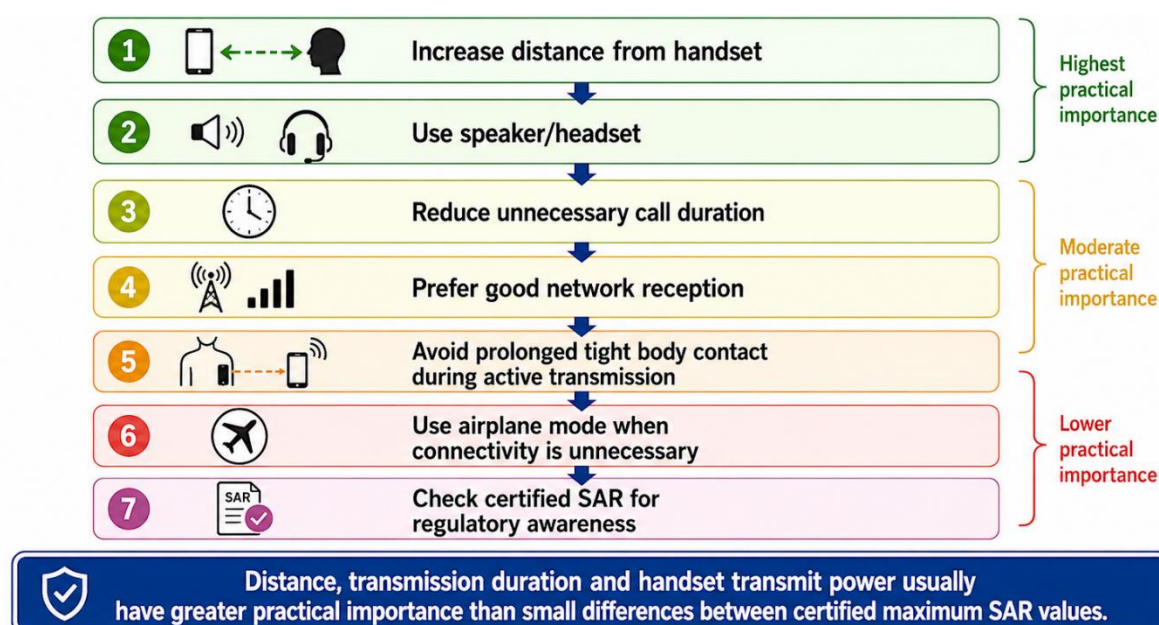


Figure 4: Practical hierarchy of simple strategies capable of reducing personal RF exposure. Source: Author’s synthesis based on ICNIRP (2020), Fontaine et al. (2026), and TEC handset requirements.

Table 4: Practical mobile-phone exposure-reduction measures. Source: Author’s synthesis based on ICNIRP (2020), Fontaine et al. (2026), and Indian TEC requirements.

Measure	Scientific rationale
Use speakerphone	Increases distance from the head
Use wired/headset communication	Keeps primary handset transmitter away from head
Shorten unnecessary calls	Reduces duration of active transmission
Prefer good network signal	May allow lower handset uplink power
Avoid prolonged body contact during active transmission	Increases separation between RF source and tissue
Place phone away from pillow/head when not needed	Increases distance
Use airplane mode when	Prevents cellular transmission

connectivity is unnecessary	
Use stable Wi-Fi appropriately	Wi-Fi connectivity may reduce cellular-network uplink emissions in some circumstances, particularly outside voice-call periods; however, Wi-Fi itself uses RF-EMF and therefore lower cellular emission should not automatically be interpreted as lower total RF exposure.
Check SAR using *#07#/manufacturer information	Improves regulatory awareness
Avoid unverified shielding products	Effectiveness may be uncertain and antenna performance may be altered

12. Research gaps and future directions: Despite extensive research, several questions merit further attention.

12.1 Objective personal dosimetry: Historical studies often relied on years of ownership or recalled call duration, which are weak proxies for absorbed RF dose. Future studies should integrate network-derived transmission data, handset logs, exposimeters, signal-quality measurements, device position, transmitted power and network generation. Real-world approaches such as Fontaine et al. (2026) represent an important advance.

12.2 Long-term 4G and 5G exposure: Many epidemiological datasets predominantly reflect earlier mobile technologies; long-duration follow-up of contemporary 4G/5G users remains necessary.

12.3 Children and lifetime exposure: Prospective studies beginning early in life could improve understanding of cumulative exposure across several decades.

12.4 Reproductive outcomes: Future studies should improve objective RF dosimetry, assessment of phone position, semen-analysis standardization and control of relevant confounding factors. Cross-species dosimetry also requires refinement to determine which exposure metrics best predict biological responses.

12.5 Independent replication and transparency: Future studies should report frequency, modulation, power, SAR or power density, exposure geometry, tissue temperature, sham controls, randomization, blinding and statistical methods, with preregistration where appropriate. Improved transparency and reproducibility are essential for resolving disputed low-level effects.

13. Balanced risk communication: Public communication often polarizes between claims that mobile-phone radiation is completely harmless and claims that it has been proven to cause cancer or multiple diseases. Neither position accurately reflects the present evidence. A balanced interpretation is that mobile-phone RF is non-ionizing, tissue heating is the established effect at sufficiently high exposure, and current restrictions are designed to prevent established adverse effects. Recent human evidence is broadly reassuring for major cancers, acute symptoms and short-term cognition, while male reproductive evidence remains uncertain and selected animal tumour signals warrant continued investigation. Certified SAR is a compliance metric rather than a personal dose meter, and actual exposure varies with distance, duration, signal quality and use conditions. Individuals who prefer a precautionary approach can reduce exposure using simple behavioural measures. Consistent with this approach, Elwood and Karipidis (2026) emphasized that human epidemiological, experimental and animal evidence should be interpreted together rather than through isolated positive or negative studies.

14. Strengths and limitations of the present review: A major strength of this review is its integrated interpretation of international guidelines, human epidemiology, controlled experiments, animal and in-vitro studies, real-world smartphone dosimetry and SAR regulation. Priority is given to recent systematic reviews and meta-analyses, while case reports and individual studies are interpreted according to their methodological weight. The review also distinguishes ionizing from non-ionizing radiation, certified SAR from real-world exposure, and established thermal effects from less-certain outcomes, while translating evidence into proportionate exposure-reduction advice.

This is a focused narrative review rather than a formal systematic review and therefore does not include PRISMA-based selection, an independent risk-of-bias assessment or a new quantitative meta-analysis. Important limitations also arise from the underlying literature: many historical studies used self-reported phone use rather than objective RF dosimetry; evidence for male fertility, childhood exposure, long-term cognition and several less-studied cancers remains limited; and much long-term epidemiology reflects earlier mobile technologies. Continued research should therefore emphasize objective real-world dosimetry, contemporary 4G/5G exposure, long-term follow-up and transparent integration of human, animal and mechanistic evidence.

15. CONCLUSION

Mobile-phone emissions are non-ionizing RF electromagnetic fields and should not be equated with X-rays or gamma radiation. Tissue heating at sufficiently high exposure is the established interaction underlying RF restrictions. SAR remains an important compliance metric, but certified maximum SAR is not an individual's real-time or cumulative dose because everyday exposure varies with transmit power, signal quality, activity, distance and duration. Current human evidence is broadly reassuring for the most studied cancers, acute symptoms and short-term cognition, whereas male fertility and several less-studied outcomes remain less certain; selected animal tumour findings warrant further investigation. Users who wish to minimize exposure can increase phone-to-body distance, use speaker mode or a wired headset, shorten unnecessary calls and avoid prolonged calling under weak-signal conditions. Future work should prioritize objective dosimetry, contemporary 4G/5G technologies and long-term follow-up while maintaining clear communication of both established findings and residual uncertainty.

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