

5G wireless communication

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Fields and waves

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To: Dr. Noha Hassan

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i. Introduction

5G is a unified, more capable air interface. It has been designed with an extended capacity to enable next-generation user experiences and deliver new services that were not provided in the previous generations, for example the 1st generation that was introduced in the 1980s delivered voice, the 3G brought mobile data in the early 2000s, and during the 2010s 4G LTE ushered in the era of mobile broadband.

- 5G is significantly faster than 4G
- 5G has more capacity than 4G
- 5G has significantly lower latency than 4G
- 5G is a unified platform that is more capable than 4G
- 5G uses spectrum better than 4G

Currently telecommunication operates with 4G and the previous generations in some cases and places of the world at frequencies below 6 GHz, including radio and TV broadcasting and wireless sources such as local area networks and mobile telephony, but 5G and future wireless telecommunication sources are planned to operate at frequencies above 6 GHz and into the 'millimeter wave' range (30–300 GHz), but these high frequencies have given rise to public concern about any possible adverse effects to human health, such as tissue heating and other biological interactions that can have both harmful as well as therapeutic effects.

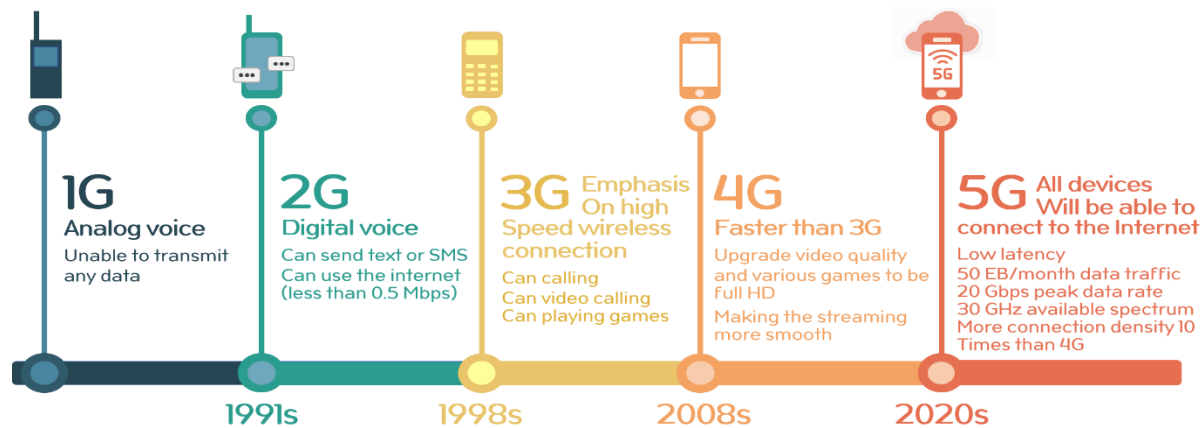


Figure 1:: Evolution of wireless communication from 1G to 5G

ii. Literature review

1) SCENIHR (2015)

This publication is an opinion update on the 2009 health effects EMF. That explores research on the mechanisms and health effects of EMF. Similar to other guidelines, this publication includes research on the entire frequency range. It foresees the future use of 5G frequencies and reports this will operate at lower exposure levels, it also reports there will be less penetration and 5G will only affect superficial tissues.

2) IARC (2012)

This is a monograph on the carcinogenic hazards to humans of RF-EMF. The paper states there is limited evidence in humans. Positive associations have been observed between exposure to radiofrequency radiation from wireless phones and glioma, and acoustic neuroma. The IARC have categorized RF-EMF as possibly carcinogenic to humans (Group 2b), this is within the same category as caffeine, talc powder, pickled vegetables (traditional Asian) and petrol engine exhaust (a full list can be found at: <https://monographs.iarc.fr/list-of-classifications-volumes/>).

3) Bio initiative Report (2014)

A report produced by a group of international scientist and health experts. The report explores the possible risks of wireless technology and electromagnetic fields. It argues that the current guidelines are not adequate and insufficiently protective for public health due only considering the energy absorption and thermal effects of RF-EMF. And do not consider the non-thermal effects of RF-EMF exposure. The authors suggest that action should be precautionary and the use of 5G should be deferred till final proof/causal evidence is established.

4) Wu, T (2015)

This is paper looks at the biological impact of millimeter wave radiation and on the human body. The paper highlights that the skin and the eyes would receive the most exposure to 5G frequencies, however it reports no ocular damage or unsafe temperature increase at the suggested exposure levels of 5G technology.

iii. Effects of 5G wireless communication on human health

Biological effects are measurable responses to a stimulus or to a change in the environment. These changes are not necessarily harmful to your health. For example, listening to music, reading a book, eating an apple or playing tennis will produce a range of biological effects. Nevertheless, none of these activities is expected to cause health effects. The body has sophisticated mechanisms to adjust to the many and varied influences we encounter in our environment. Ongoing change forms a normal part of our lives. But, of course, the body does not possess adequate compensation mechanisms for all biological effects. Changes that are irreversible and stress the system for long periods of time may constitute a health hazard.

An adverse health effect causes detectable impairment of the health of the exposed individual or of his or her offspring; a biological effect, on the other hand, may or may not result in an adverse health effect.

It is not disputed that electromagnetic fields above certain levels can trigger biological effects. Experiments with healthy volunteers indicate that short-term exposure at the levels present in the environment or in the home do not cause any apparent detrimental effects. Exposures to higher levels that might be harmful are restricted by national and international guidelines. The current debate is centered on whether long-term low level exposure can evoke biological responses and influence people's wellbeing.

According to the World Health Organization (WHO) Trusted Source, there is limited research on the frequencies used in 5G.

There is more research on the health effects of electromagnetic fields across the spectrum. However, the results are inconsistent.

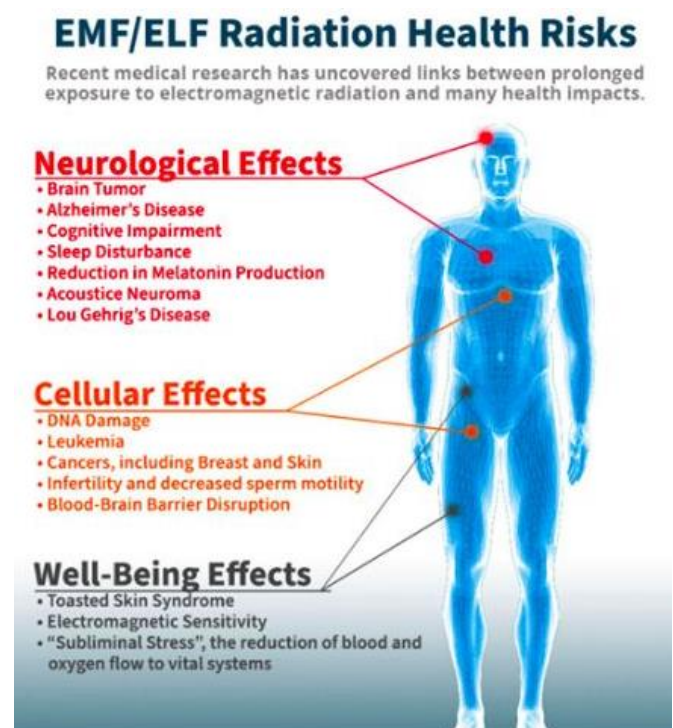


Figure 2: 5G effects

To date, EMFs have been potentially associated with:

1) Tissue heating

A small 2017 study showed that mobile phones use frequencies of 1.8 to 2.2 GHz. These frequencies cause tissue heating, according to WHO.

Tissue heating occurs when your skin absorbs electromagnetic energy. This causes a slight rise in temperature in your brain and body.

A 2021 study also found that people experience more EMF-related tissue heating as they get older. Plus, the higher the EMFs, the more they absorb. That's because older individuals tend to have reduced skin thickness and blood flow.

However, tissue heating is short-term and minimal. The Federal Communications Commission (FCC) also states that the public is exposed to very low frequencies of EMFs. These levels are too low to cause considerable tissue heating.

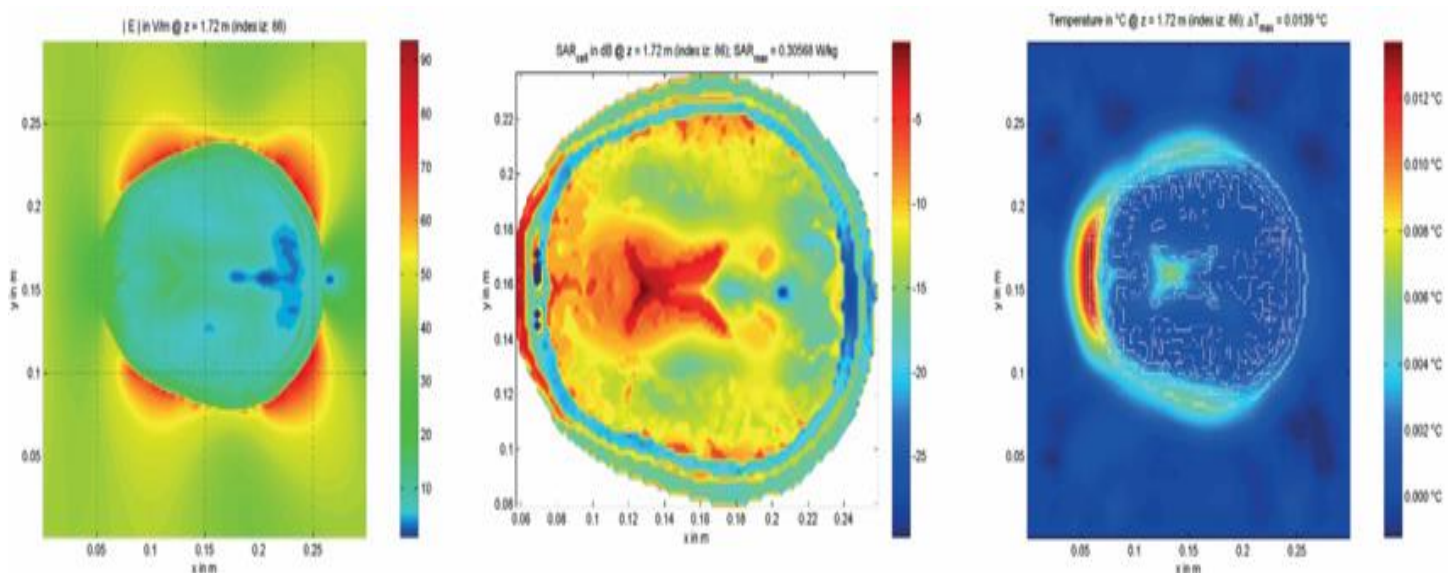


Figure 3: EMF and temperature effects

2)Cognitive function

The effects of 5G exposure on cognitive function have not been studied yet.

In a small 2017 study, researchers examined how using a mobile phone affects cognitive function. The researchers found that using a mobile phone for at least 90 minutes a day is associated with attention difficulties.

A small 2018 research review found conflicting evidence. The researchers examined 43 studies regarding EMFs and cognitive function. They concluded that there is no solid link between EMFs and cognitive concerns.

3)Cancer

In 2011, the International Agency for Research on Cancer (IARC) stated EMFs are “possibly carcinogenic” to humans. The classification was determined by 30 scientists from 14 countries.

To date, most studies have examined the potential link between EMFs and brain cancer. But the results have been inconsistent.

For example, a 2017 research review found that EMF radiation from mobile phones are associated with glioma, a type of brain cancer. A 2018 study, on the other hand, did not find a clear association between high frequency EMFs and brain tumors.

Again, more studies are needed to determine if 5G frequency can contribute to cancer development.

4)Effects on pregnancy outcome

Many different sources and exposures to electromagnetic fields in the living and working environment, including computer screens, water beds and electric blankets, radiofrequency welding machines, diathermy equipment and radar, have been evaluated by the WHO and other organizations.

The overall weight of evidence shows that exposure to fields at typical environmental levels does not increase the risk of any adverse outcome such as spontaneous abortions, malformations, low birth weight, and congenital diseases. There have been occasional reports of associations between health problems and presumed exposure to electromagnetic fields, such as reports of prematurity and low birth weight in children of workers in the electronics industry, but these have not been regarded by the scientific community as being necessarily caused by the field exposures (as opposed to factors such as exposure to solvents).

5) Electromagnetic hypersensitivity and depression

Some individuals report "hypersensitivity" to electric or magnetic fields. They ask whether aches and pains, headaches, depression, lethargy, sleeping disorders, and even convulsions and epileptic seizures could be associated with electromagnetic field exposure.

There is little scientific evidence to support the idea of electromagnetic hypersensitivity. Recent Scandinavian studies found that individuals do not show consistent reactions under properly controlled conditions of electromagnetic field exposure. Nor is there any accepted biological mechanism to explain hypersensitivity. Research on this subject is difficult because many other subjective responses may be involved, apart from direct effects of fields themselves. More studies are continuing on the subject.

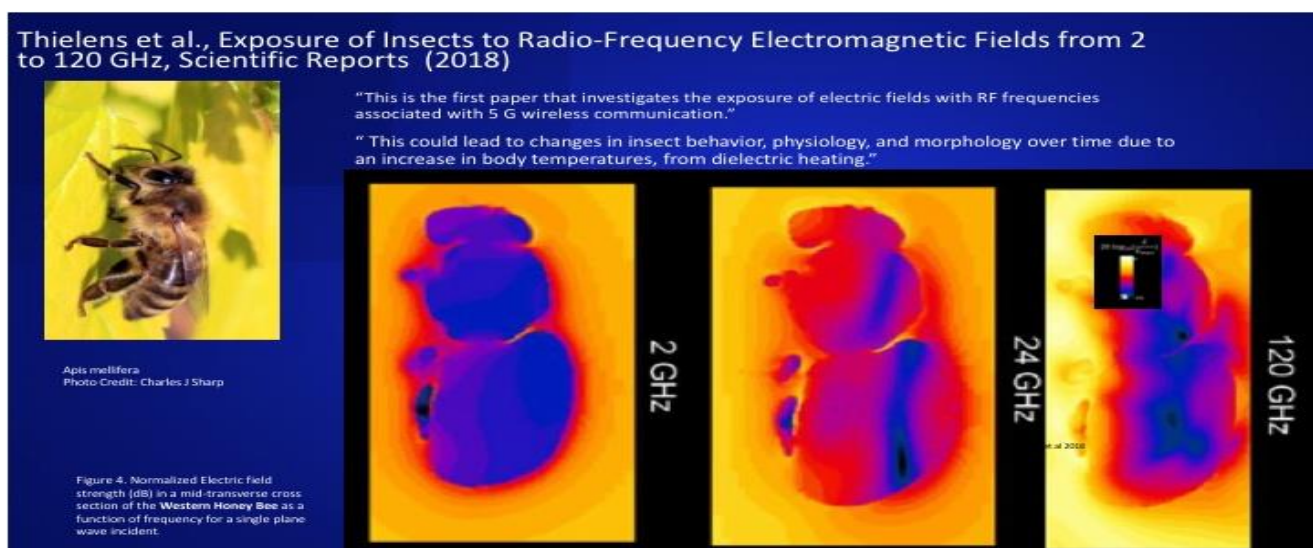


Figure 4: EMF effects at different frequencies

6) Cataracts

General eye irritation and cataracts have sometimes been reported in workers exposed to high levels of radiofrequency and microwave radiation, but animal studies do not support the idea that such forms of eye damage can be produced at levels that are not thermally hazardous. There is no evidence that these effects occur at levels experienced by the public.

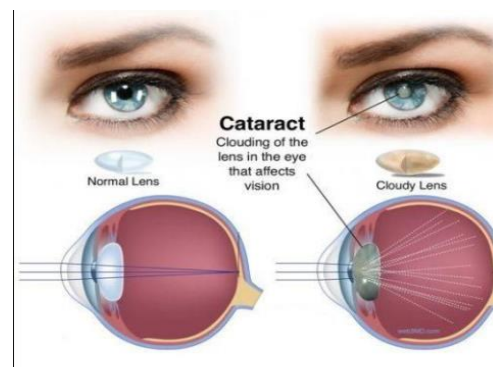


Figure 5: cataract

7) Male infertility

According to a 2014 animal study, long-term exposure to EM radiation reduces the reproductive function of male rats.

In a 2015 study Trusted Source, researchers examined the sperm motility of more than 1,000 men. The men answered questions about their Wi-Fi and cell phone use. Researchers determined that men who used wireless internet had reduced sperm motility, compared with men who used wired internet.

But the researchers didn't state the possible mechanisms behind these results. They also noted that the questionnaire didn't ask if participants were smokers. Smoking may affect sperm motility.

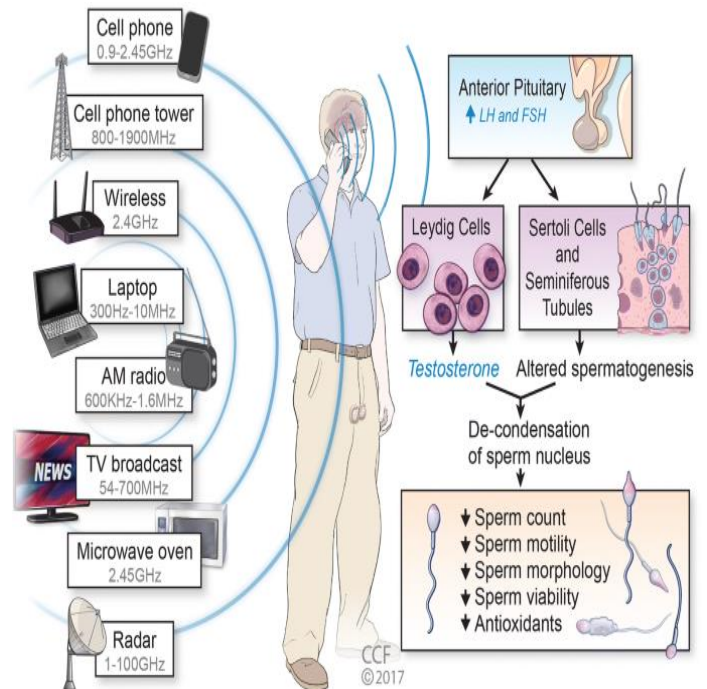


Figure 6: male infertility due to EMF

A 2016 animal study found that radiation emitted from Wi-Fi (EM radiation) causes DNA damage in the testes of rats.

iv. Public concern about possible adverse effects to human health due to exposure to RF fields from 5 G and other sources

Some members of the public have attributed a diffuse collection of symptoms to low levels of exposure to electromagnetic fields at home. Reported symptoms include headaches, anxiety, suicide and depression, nausea, fatigue and loss of libido. To date, scientific evidence does not support a link between these symptoms and exposure to electromagnetic fields. At least some of these health problems may be caused by noise or other factors in the environment, or by anxiety related to the presence of new technologies.

The public have concerns over EMF in general and 5G as it's a rising and relatedly new to the world, thus there've been several myths about its effects on health.

Some of the claims are:

- autism
- skin issues
- headaches
- pain
- dizziness
- nausea
- fatigue
- heart palpitations
- 5G directly spreads SARS CoV-2, the virus that causes COVID-19
- 5G impairs your immune system, increasing your risk of contracting SARS CoV-2
- 5G is a cover for the COVID-19 pandemic
- COVID-19 vaccines contain 5G microchips
- COVID-19 first appeared in Wuhan, China, because it was the first city to use 5G

But there's no hard evidence that wireless communication in general and 5G in specific is linked to these conditions.

v. The interaction mechanism with the human body at 5G

In the RF range, which means beyond frequencies that are high enough that cellular stimulation is no longer possible, the EMF energy absorption and subsequent tissue heating becomes the major mechanism. In this frequency range in the far field electric and magnetic field strengths are tightly coupled like the links of a chain.

RF EMF energy absorption is based on oscillating mechanical forces on electric charged particles or electric dipoles generated by the electric component, and generated by the magnetic field component on particles with an inherent magnetic moment.

Depending on the particle's mass and mobility, these forces may cause translatory, oscillatory and/or rotatory movement and hence conversion of field energy to particle's kinetic energy.

In the following step, inside the material particle's kinetic energy is distributed by collision with other particles, hence causing irregular particle movement that on a macroscopic scale is named heat (Brown's molecular movement) and quantified by the physical term temperature. It must be stressed that on a molecular level by its principal nature the interaction of RF EMF is non-thermal.

Irrespective of the field amplitude the basic physical interaction mechanism is non-thermal. However, the (macroscopic) biochemical and physiological responses depend on temperature. Most chemical properties, chemical reaction kinetics and cellular processes are temperature dependent. Therefore, any claimed borderline between thermal and non-thermal effects necessarily needs to be defined with regards to specific effects such as triggering the onset of thermoregulatory reactions. Therefore, to generally claim that effects observed below exposure limits would necessarily be non-thermal is misleading and ignores this basic relationship. If strong enough, time-varying fields (with frequencies above 100 kHz) result in measurable heating of exposed tissues (WHO, 1993, ICNIRP, 1998). If the exposure is sufficiently prolonged or intense, the capabilities of the various elements of the thermoregulatory system to dissipate the absorbed power may be compromised, resulting in increases in (whole-body or local) temperature.

Public exposures guidelines for EMF are set to avoid adverse effects on the nervous system and stimulation of nerve and muscle cells and to avoid excess heating of either the whole body or parts of it by limiting exposures to stay sufficiently below the thresholds for these effects with a reduction factor that accounts for uncertainty and interpersonal variability.

vi. The guidelines developed by the International Commission on Non-ionizing Radiation Protection (ICNIRP)

ICNIRP is an independent non-profit scientific organization responsible for providing guidance and advice on the health hazards of non-ionizing (This part of the spectrum has insufficient energy to cause ionization these include radio frequency waves) radiation exposure, The Guidelines on Limiting Exposure to Electromagnetic Fields are for the protection of humans exposed to radiofrequency electromagnetic fields (RF) in the range 100 kHz to 300 GHz, also they cover many applications such as 5G technologies, Wi-Fi, Bluetooth, mobile phones, and base stations,

How the guidelines were put:

- First, the ICNIRP identify scientific data on effects of exposure to the radiation
- Second, from this data, effects are determined considered both:
 - Adverse to humans
 - Scientifically substantiated

Which means there are enough scientific evidence to state that the effects are real,
- Third, the minimum exposure level that needed to produce harm are identified
- Fourth apply reduction factors
 - Larger for public than for workers

The ICNIRP guidelines include basic restrictions for occupational exposure and for public exposure

Table 4 Basic restrictions for time varying electric and magnetic fields for frequencies up to 10 GHz.

Exposure characteristics	Frequency range	Current density for head and trunk (mA m ⁻²)(rms)	Whole-body average SAR (W kg ⁻¹)	Localized SAR (head and trunk) (W kg ⁻¹)	Localized SAR (limbs) (W kg ⁻¹)
Occupational exposure	up to 1 Hz	40	—	—	—
	1–4 Hz	40/ <i>f</i>	—	—	—
	4 Hz–1 kHz	10	—	—	—
	1–100 kHz	<i>f</i> /100	—	—	—
	100 kHz–10 MHz	<i>f</i> /100	0.4	10	20
General public exposure	10 MHz–10 GHz	—	0.4	10	20
	up to 1 Hz	8	—	—	—
	1–4 Hz	8/ <i>f</i>	—	—	—
	4 Hz–1 kHz	2	—	—	—
	1–100 kHz	<i>f</i> /500	—	—	—
	100 kHz–10 MHz	<i>f</i> /500	0.08	2	4
	10 MHz–10 GHz	—	0.08	2	4

Figure 7: basic restrictions for electric and magnetic field

Where f is the frequency in hertz, all SAR values are averaged over a period of time equals to 6 minutes

Then coming to the guidelines, they report consideration of three primary biological effects from RF-EMF:

- **Nerve Stimulation:**

Frequencies up to 10MHz can stimulate nerves, this range of frequencies are below than those for the 5G.

- **Membrane permeabilization:**

Pulsed EMF at low frequencies can cause cells to become permeable which leads to cellular level changes, Cell permeabilization has been reported at frequencies of 18GHz in Vitro

- **Temperature elevations:**

RF can generate heat in the body, however research has shown that for low levels of exposure the amount of heat generated is not sufficient to cause harm, The guidelines report that of frequencies at 6-300 GHz, which is the 5G range, are absorbed superficially into the surface of skin, and any small rise in temperature are easily handled through thermoregulation although there is no evidence of the 5G frequencies affecting core body temperature

- **Neuroendocrine system:**

In vitro studies have shown RF-EMF can influence the neuroendocrine system, but there is no evidence this translates to humans.

- **Immune system and hematology:**

Currently there is no evidence to indicate RF-EMF affects health in humans via the immune system or hematology.

vii. Are there possible therapeutic effects at these frequencies: examples

The frequency bands for 5G networks come in two sets. Frequency range 1 is from 450 MHz to 6 GHz. Frequency range 2 is from 24.25 GHz to 52.6 GHz, among these frequencies, there are some therapeutic applications that use electromagnetic waves in these frequency bands.

So, YES, there are therapeutic effects of the frequency range that the 5G belongs to.

Examples:

- Pain relief

Millimeter wave therapy (MWT), a non-invasive complementary therapeutic technique is claimed to possess analgesic properties.

MWT was reported to be effective in the treatment of headache, arthritic, neuropathic and acute postoperative pain. The rapid onset of pain relief during MWT lasting hours to days after, remote to the site of, was the most characteristic feature in MWT application for pain relief.

The most commonly used parameters of MWT were the MW frequencies between 30 and 70 GHz and power density up to 10 mW cm⁻².

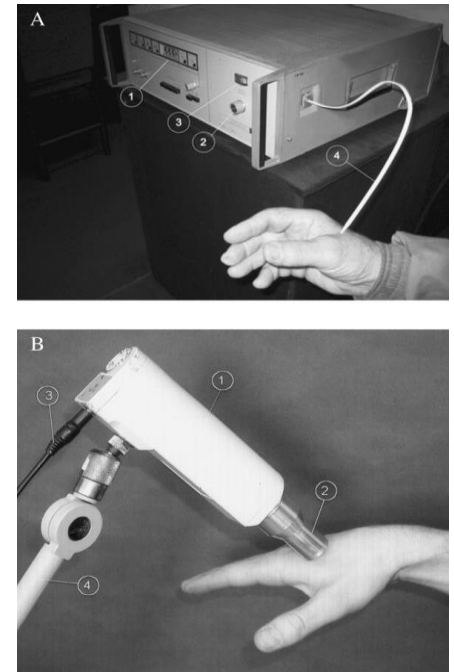


Figure 8: MWT

Pain syndrome	Disease/underlying condition	N	MW frequency (GHz)	Power density (mW cm ⁻²)	Site of MW application	Design	Oxford scale	Source/year
Experimental pain	Immersion in cold water	12	42.25	30	Lower third of sternum	RCT crossover	5	(21)/1999
Headache	Cerebral atherosclerosis	204	54–78	0.003	Carotid sinus, vertebral arteries	nRCT	0	(22)/1998
Joint pain	Essential hypertension	56	60–63	Missed	AP	RCT	1	(23)/1992
	Primary OA	114	55–62	0.01	AP	RCT	1	(25)/1998
	JRA	138	53.5		AP	RCT	1	(26)/1996
	DCTD	12	54–78	2.5	Periarticular tender points	Case series	0	(27)/2003
Postoperative pain	RA	12	54–64	2.5	AP	RCT	5	(28)/2003
	Brain lesions	42	42.25 & 53.5	10	Hands and feet	Case series	0	(29)/1998

Figure 9: Pain relief frequency ranges Examples

- Thermal magnetic resonance

A non-invasive applicator was constructed utilizing the magnetic resonance (MR) spin excitation frequency for controlled RF hyperthermia and MR imaging in an integrated system, which we refer to as thermal MR. Applicator designs at RF frequencies 300 MHz, 500 MHz and 1GHz were investigated and examined for absolute applicable thermal dose and temperature hotspot size. Electromagnetic field (EMF) and temperature simulations were performed in human voxel models. RF heating experiments were conducted at 300 MHz and 500 MHz to characterize the applicator performance and validate the simulations.



Figure 10: Thermal MR project info

viii. The application of 5G wireless transmission technology in healthcare.

When people hear the word 5G they always relate it to faster internet only, but as the figure below illustrates it's related to all industries

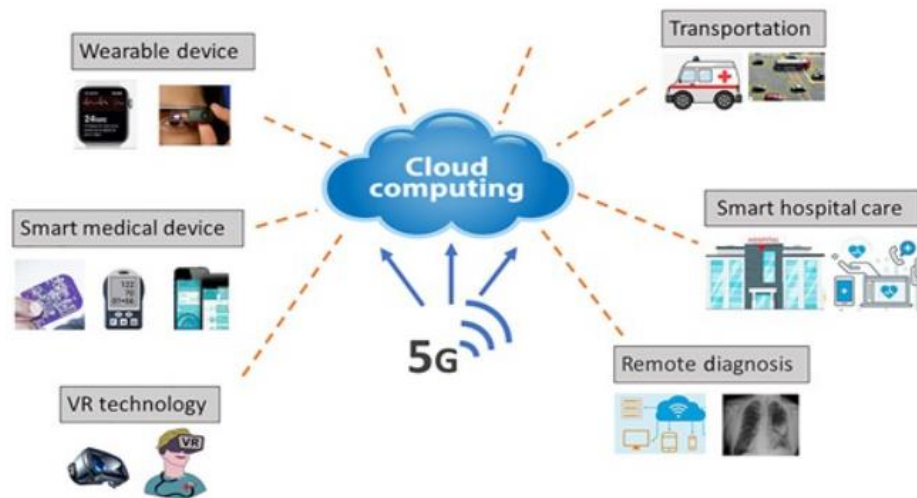


Figure 11:5G applications

Every sector and industry, including healthcare, the development of fifth generation wireless networks (5G), have created an extraordinary opportunity to create an integrated ecosystem for new opportunities for each of them, Healthcare would benefit greatly from reliable internet connectivity for medical devices, with greater bandwidth and super coverage and availability than provided by 4G LTE, Specially after covid-19, lots of attention has focused on 5G's potential to support telehealth services, which is the delivery of health care, health education, and health information services via remote technologies, or doctor's visits conducted via computer which is helpful for the required physical distance or when patients are far away from healthcare facilities,

Adding sensors and virtual reality (VR) enables workers to monitor vital signs continuously and send help if there's need, and looking to the fact that huge package of data can be transmitted fast, testing patients with conditions for changes in their heartbeat, blood sugar, and blood pressure multiple times a day using cloud-linked scanners is also possible like using smartwatches, Promotion of the integration of VR and AR is critical for comprehensive rehabilitation training, as most of rehabilitation now is done remotely so that it's better for both the

patient to follow his vital signs and realize the progress and also for the doctor or advisor to prevent long distance and also the progress will be more accurate to judge,

The application of VR in healthcare is not a new technology emerging in the 5G era, but with its innate high bandwidth and low latency advantage, VR is expected to help streamline the entire hospital, especially in telemedicine, teleconsultation, and even remote surgery which is the ability for a doctor to perform surgery on a patient even though they are not physically in the same location, It is a form of telepresence, it contains a robot generally consists of one or more arms, a master controller, and a sensory system giving feedback to the patient and the doctor, also rather than the dominant doctor-centered diagnosis and treatment way, the self-determination will significantly enhance the patient's autonomy by giving the patient participation throughout the entire treatment system, the diagnosis and treatment plan will be timely, dynamic, and interactive allowing for individual feedback with regards to lifestyle elements, behavioral factors, and treatment effect, to help patients to become more dependent from clinical services.

Patients that their cases are being followed remotely, the risk of their situations are monitored by wireless body sensor network (WBSN), Health risk assessment based on decision making algorithm determines the patient's health condition severity level routinely and each time a critical issue is detected based on vital signs scores that are being sent, which means their health is continuously monitored,

The severity level is represented by a risk variable whose values range between 0 and 1, the higher the risk value, the more critical the patient's health condition is and the more it requires medical attention, and an ambulance is sent quickly to move the patient to hospital as soon as possible,

As an addition the score of a vital sign is calculated using its past and current value, thus assessing its status based on its evolution during a period of time and not only on sudden deviations,

This technology might face some problems which is the energy consumed by the biosensor nodes for sensing and transmitting since important physiological variations can be missed out and the data fusion process can be affected if one or more biosensor nodes are dead but no case faced this problem till now according to the paper of health risk assessment,

ix. Conclusion

As technology are involving day by day we shouldn't only be impressed by how fast or how it can make our life easier, there's a price and consequences for everything, just like iPhones most people in world prefer using them over other products, but according to some research they radiate more electromagnetic wave than the other competitors, so before buying or using new technology we should search about the hazards on health and consequences of using it over a long term to see if we can handle the cons or how to use it well to get the least harm like the advice on leaving any electronic devices out of the sleeping room to get more comfortable sleep, we should follow the same advice concept to get a better health life.

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