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5 G wireless telecommunications expansion: Public health and environmental implications☆

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ABSTRACT

The popularity, widespread use and increasing dependency on wireless technologies has spawned a telecommunications industrial revolution with increasing public exposure to broader and higher frequencies of the electromagnetic spectrum to transmit data through a variety of devices and infrastructure. On the horizon, a new generation of even shorter high frequency 5G wavelengths is being proposed to power the Internet of Things (IoT). The IoT promises us convenient and easy lifestyles with a massive 5G interconnected telecommunications network, however, the expansion of broadband with shorter wavelength radiofrequency radiation highlights the concern that health and safety issues remain unknown. Controversy continues with regards to harm from current 2G, 3G and 4G wireless technologies. 5G technologies are far less studied for human or environmental effects.

It is argued that the addition of this added high frequency 5G radiation to an already complex mix of lower frequencies, will contribute to a negative public health outcome both from both physical and mental health perspectives.

Radiofrequency radiation (RF) is increasingly being recognized as a new form of environmental pollution. Like other common toxic exposures, the effects of radiofrequency electromagnetic radiation (RF EMR) will be problematic if not impossible to sort out epidemiologically as there no longer remains an unexposed control group. This is especially important considering these effects are likely magnified by synergistic toxic exposures and other common health risk behaviors. Effects can also be non-linear. Because this is the first generation to have cradle-to-grave lifespan exposure to this level of man-made microwave (RF EMR) radiofrequencies, it will be years or decades before the true health consequences are known. Precaution in the roll out of this new technology is strongly indicated.

This article will review relevant electromagnetic frequencies, exposure standards and current scientific literature on the health implications of 2G, 3G, 4G exposure, including some of the available literature on 5G frequencies. The question of what constitutes a public health issue will be raised, as well as the need for a precautionary approach in advancing new wireless technologies.

1. Introduction

The adoption of new 5G technology promises to give the public a transformative communication network with an explosion of speed, volume of data and number of devices with unlimited computing instantly to anyone in the world. High tech companies are already marketing the Internet of Things to businesses, healthcare systems, schools and the public. The promise to connect our phones and appliances, will virtually eliminate many day-to-day household and business functions including driving. This will, according to industry, create a superior, connected society and unprecedented economic growth. What is missing in this discussion is the maturing literature on adverse biological, physiological, and psychological health effects of the 2G, 3G, and 4G radiofrequencies we are already exposed to, in addition to indications from the scientific literature that 5G frequencies could also be hazardous.

Many important but unanswered questions merit serious consideration. Is the widespread deployment of this pervasive higher frequency small cell distributed antennae system in our cities and on our homes safe for humans and the environment? Will it add to the burden of chronic disease that costs our nation, according to the CDC, an estimated 2.3 trillion dollars annually (CDC, 2017)? Are we already digitally over connected, shrinking our gray matter and becoming a dysfunctional addicted nation because of it (Weng et al., 2012)? How

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will this affect our privacy, cyber security and the security of our medical records? Will physicians be able to recognize the emerging adverse health effects of new millimeter technology let alone that of current wireless devices? These important questions have not been addressed, yet industry and government policy have already moved forward with advertising, manufacturing and legislating the adoption of these new technologies.

2. Methods

A review of the literature was performed which included health effects of wireless technologies, controversies related to radiofrequency health effects, telecommunications 5G innovations and specifications for wireless technology as well as related policies affecting public health.

3. Results

3.1. Controversy persists as evidence of harm increases

The controversy over health effects of radiofrequency electromagnetic radiation (RF EMR) from commonly used wireless devices such as cell phones, cordless phones, WiFi routers and cell tower infrastructure remains problematic. RF research in the U.S. is poorly funded and even when a study is robust it never seems to answer the question of long term safety or provide appropriate precautionary limits. (Wyde, 2016). In 2011 the International Agency on Research on Cancer (IARC) listed non-ionizing radiofrequency radiation from cell phones and other wireless devices in Group 2B: Possibly carcinogenic to humans, based on a thorough analysis of current scientific evidence (IARC, 2011; IARC, 2017). Some researchers feel this listing should be changed to a Group 2A: Probably carcinogenic to humans or to Group 1: Carcinogenic to humans classification (Morgan et al., 2015; Sage and Carpenter, 2012). This is based on the recent National Toxicology Program Carcinogenicity Studies of Cell Phone Radiofrequency Radiation that report a significant increase in heart and brain tumors with RF-EMR exposure (Wyde, 2016). This is in addition to the abundance of basic scientific studies that show a clear health risk associated with exposure to radiofrequencies, especially with long term exposure (Hardell et al., 2013a, 2013b; Adams et al.al., 2014; Bortkiewicz et al., 2017; Carlberg and Hardell, 2017; Hassanshahi et al., 2017; Liu et al., 2014; Levitt and Lai, 2010). Many of these studies demonstrate effects well below the heat threshold of current safety standards (Wyde, 2016; IARC, 2011; Sage and Carpenter, 2012; EPA, 1992; Esmekaya et al., 2011; Grigoriev et al., 2010; Belyaev, 2005; Yu and Yao, 2010). Radiofrequencies are absorbed by and pass through living systems that contain water. Pregnant women and children are more vulnerable to developmental harm from microwave radiation due to immature organ systems (Birks et al., 2017; Othman et al., 2017a, 2017b). Research also shows children absorb more microwave radiation per body weight than an adult, however, standards were developed for adult bodies (Morgan et al., 2014).

3.1.1. Industry bias and scientific results

Industry continues to state that the weight of evidence regarding harm from RF-EMR is inconclusive. Studies that review the sources of funding and scientific bias regarding cell phones and brain cancer indicate otherwise. Huss et al. (2007) performed a systematic review regarding the association of cell phone use and brain tumors in relation to funding. He found that industry studies showed a positive association 33% of the time, whereas non-industry studies showed an 82% association. In addition, they discovered that none of the 31 peer reviewed journals listed conflicts of interest for the authors.

Myung et al. (2009) performed a meta-analysis and found that there was a small but significant elevation in brain tumors with long term cell phone use when high quality studies were examined. He noted Hardell's research to be more robust, as “all of the studies by Hardell et al. used blinding to the status of patient cases or controls at the interview and were categorized as having a high methodologic quality when assessed based on the NOS, whereas most of the INTERPHONE-related studies and studies by other groups did not use blinding and were thus categorized as having low methodologic quality”. Prasad et al. (2017) investigated the results of 22 case-controlled studies which showed an increased risk of brain tumor with long-term exposure to mobile phone radiation while industry-funded research tended to underestimate the risk.

An analysis of the Interphone study by Morgan (2009) noted eleven design flaws, including1) selection bias, 2) insufficient latency time, 3) definition of 'regular' cellphone user, 4) exclusion of young adults and children, 5) no cosideration for cell phone exposure in rural areas where they would be radiating at higher power levels, 6) exposure to other transmitting sources are excluded, 7) exclusion of brain tumor types, 8) recall accuracy of cellphone use, and 9) funding bias.

In the first court case to award damages to a plaintiff for a brain tumor caused by cell phones, an Italian court excluded cancer-based studies related to cellphones that had been financed by telecommunications companies., according to a news articles (Williams, 2017).

3.2. Current Federal Communications Commission (FCC) radiofrequency guidelines

Physicists and engineers point out that non-ionizing radiofrequency radiation, which we use in modern telecommunications today, has too low an energy unit per photon to move electrons in an atom, causing ionization, as seen with radiation from X-rays and radioactive materials (WHO, 1981). They argue that heat is the only measure of harm which is meaningful with regards to health and safety of RF EMR. Scientists, however, have elucidated other mechanisms whereby cellular functioning can be disrupted by non-thermal exposures to radiofrequency radiation.

Current FCC Guidelines for non-ionizing radiation exposure were developed over two decades ago and are based on heating of tissues over short exposure periods (6 min for occupational/controlled and 30 min for public/uncontrolled exposure) (FCC, 1997, 2015; FCC, 2013). There are no long term exposure guidelines, nor are there guidelines for low level, non-thermal or biological effects considered in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) standards which are the basis for standards used worldwide (ICNIRP, 2009; Hardell, 2017).

With the passage of the federal Telecommunication Act of 1996 responsibility for safety of non-ionizing radiation was passed from the EPA to the FCC (1996). At the time, the EPA was preparing recommendations for long term exposure which were not included in the FCC guidelines (EPA, 1981; EPA, 1992). In a 1993 scientific conference sponsored by the US EPA Office of Air and Radiation and the Office of Research and Development, the EPA discussed its concerns about public RF exposure and the need for additional research. The report noted health issues that remained unsolved including “potential effects of long term, low level exposure; and biophysical mechanisms.” (EPA, 1993).

A World Health Organization summary of Environmental Health Criteria from a Warsaw conference in 1973 stated “More data on the relationship between biological and health effects and the frequency and mode of generation of the radiation, particularly in complex modulations, are needed.” They further state, “Prevention of potential hazards is a more efficient and economical way of achieving control than belated efforts to reduce existing levels.” (WHO, 1981).

Sage and Carpenter, among others, note that for adequate public health protection a biological safety standard is needed that considers current research indicating cellular harm, long term effects of constant exposure and effects on vulnerable populations (Sage and Carpenter, 2012; Blank et al., 2015). FCC recommendations have not been updated to include current literature on cellular affects at levels below FCC guidelines or effects of long term exposure (EPA Letter, 2002). It is notable that Section 704 of the 1996 Telecommunications Act specifies the following: "Section 704(a) of the 1996 Act expressly preempts state and local government regulation of the placement, construction, and modification of personal wireless service facilities on the basis of the environmental effects of radio frequency emissions to the extent that such facilities comply with the FCC's regulations concerning such emissions (FCC, 1996). This policy directly contradicts current evidence of harm.

3.2.1. FCC guidelines and specific absorption rate

In 1985, the FCC adopted thermal guidelines to be used for evaluating human exposure to radiofrequency (RF) emissions, incorporating electric and magnetic field strength and power density limits for Maximum Permissible Exposure (MPE) for transmitters operating at frequencies between 300 kHz and 100 GHz. These were updated in 1996. Limits are defined by either Specific Absorption Rate (SAR) or power density (PD). SAR is a measure of heat absorption in the body expressed in watts per kilogram and is typically used for near field exposure to cell phones and wireless devices. For the general population the SAR limit in the U.S. is 0.08 W/kg as averaged over the whole-body and for localized heating (typically for cell phones) the SAR limit should not exceed 1.6 W/kg as averaged over any 1 g of tissue. These SAR standards apply at operating frequencies between 100 kHz and 6 GHz (ICNIRP, 2009). This guideline gives a heating safety factor of 50 (ICNIRP, 2009; Hardell, 2017).

The closer the device is to the body, the higher the absorption of radiation and heat generated, thus in manufacturers device information inserts, the SAR is usually listed with safety recommendations for limiting close proximity to the body. The recommendation for devices such as tablets and portable laptop computers in FCC documents Page 5 states "For purposes of RF exposure evaluation, a mobile device is defined as a transmitting device designed to be used in other than fixed locations and to be generally used in such a way that a separation distance of at least 20 cm is normally maintained between the transmitter's radiating structures and the body of the user or nearby persons." (FCC, 1997).

For cell phones, the distance from the head to comply with SAR standards varies between different phones and manufacturers. Usually a minimum separation of millimeters from the head is noted in the manufactures literature. For example, the Samsung model SM-G920A insert states "Body-worn SAR testing has been carried out at a separation distance of 1.5 cm. To meet RF exposure guidelines during body-worn operation, the device should be positioned at least this distance away from the body." (Samsung SAR) Although implantable medical devices are now shielded from external RF EMR to prevent interference, manufactures may still include safety information. Samsung notes, "A minimum separation of six (6) inches should be maintained between a handheld wireless mobile device and an implantable medical device, such as a pacemaker or implantable cardioverter defibrillator, to avoid potential interference with the device." (Samsung Guide).

3.2.2. Higher frequency radiation FCC measurement standards: 6–100 Ghz

For higher frequencies energy is measured as power per unit area or power density (PD). Power density is typically expressed in terms of watts per square meter (W/m^2) or milliwatts per square centimeter meter (mW/cm^2). The conversion is 10 W/m = 1 mW/cm^2. It is also expressed as microwatts per square centimeter (μW/cm^2) for lower power measurements (1 mW/cm^2 = 1000 μW/m^2) (SLAC, 2015). Power density limits vary with frequency but at cell phone frequencies of 1500 MHz the FCC limit is 1 mW/cm^2 (or 1000 μW/m^2) in the U.S. (Madjar, 2016). The FCC notes in the OET Bulletin 65, that "devices that operate above 6 GHz (*e.g.,* millimeter-wave devices) localized SAR is not an appropriate means for evaluating exposure. At these higher frequencies, exposure from portable devices should be evaluated in terms of power density MPE limits instead of SAR." (FCC, 1997).

3.2.3. EMR frequencies

Wireless communication uses electromagnetic frequencies to carry data through the air. Typically, this includes both a carrier wave and an operating wave. Frequency is measured in cycles per second. 1 Hz (Hz) is one cycle per second. A Kilohertz (KHz) is 1000 cycles per second, a Megahertz (MHz) is a million cycles per second and a Gigahertz (GHz) pulses at a billion cycles per second. The typical 2.4 GHz Wi-Fi pulses at 2.4 billion cycles per second. Broadband was introduced in the 2000's as a high capacity transmission technology that allows a wide band of radio frequencies to operate simultaneously. This multiple frequency technology can be delivered with copper wires, fiberoptic, cables or through wireless transmission (Chiou, 2005; Goleniewski, 2001). In order to carry data at faster speeds, each new generation of telecommunications uses higher frequency radio waves. The higher frequencies used for new technology are added to the existing frequencies of older technology (Chávez-Santiago et al., 2015; 5G Vision EU). This creates an increasing mix of electromagnetic frequency exposures.

3.2.4. The electromagnetic spectrum and wireless devices

Radio frequency (RF) comprises a continuum of the electromagnetic spectrum wavelengths below visible and infrared light from about 3 kHz to 300 GHz. The wavelengths in the radio frequency range in size from hundreds of meters to fractions of a a centimeter.

Radio communications operate with long waves that are a meter to many kilometers wide. These are in the 3 Hz to 300 MHz band. AM Radio operates from 540 to 1600 kHz. FM Radio operates from 76 to 108 MHz. Long radio communication wavelengths are also known as groundwaves and can follow the earths contours beyond the horizon an thus transmit far distances.

Microwave radio frequencies are 300 MHz to 300 GHz. Higher frequency and shorter wavelength radio frequencies (microwaves) are now widely used in modern digital communications. First generation (1G) to Fourth generation (4G) radio frequency wavelengths are centimeters to a meter in width and were first used in military communications decades ago. These shorter wavelengths transmit information in a straight line of sight path but for shorter distances. Cell towers thus can transmit dozens of miles away versus typical radio communication towers that can transmit for 100's of miles, depending on the power output, height of the tower, weather and topography. New proposed 5G small cells, with millimeter waves, will transmit only 300 m.

As telecommunication has advanced, the frequencies used have shorter wavelengths and faster data transfer. More data channels can be compressed into the shorter frequency bands enabling more data to be transferred simultaneously. This means more data at faster speeds. Older cell phones and cordless DECT phones use 900 and 1800 MHz wavelengths. Today almost all newer wireless devices use a small range of frequencies clustered near 2.4 GHz, *i.e.* Cell phones, cordless phones, Wi-Fi routers, and Bluetooth. This is the same frequency as microwave ovens but with much less power. To eliminate interference from multiple devices, 5.0 GHz frequencies have been introduced into newer wireless devices. Smart meters operate with both a 900 and 2.4 GHz signals.

Proposed fifth generation (5G) technologies will use frequencies between 30 and 100 GHz which are shorter millimeter wavelengths (1–10 mm) (Nordrum, 2017). This technology is said to carry wireless data 10 times faster than 4G with 1000 times the data.

3.2.5. Generational cell phone frequencies

1G - Analog- Advanced Mobile Phone Service (AMPS) was commercially introduced in the 1980's and operated with voice only at 800 MHz with a continuous wave signal.

2G - Global System for Mobile Communications (GSM) and Code Division Multiple Access (CDMA), are variants of 2G systems, introduced in 1990's providing text messaging, multimedia messaging and internet access. These were used in the first digital cell phones. Frequencies are a combination of 850 and 1900 or 900 and 1800 MHz.

3G - Universal Mobile Telecommunications Service (UMTS)- Introduced in 1998 with broadband features providing data transfer, mobile internet and video calling. There are dozens of frequency bands available in the 800–900 MHz range and the 1700–2100 MHz range depending on the carrier.

4G - Long Term Evolution (LTE) –Was released in 2008 with higher frequency broadband supporting faster web access, gaming, video conferencing, and HD Mobile TV. These frequencies are in the 700 MHz, 1700/2100 MHz and the 2500–2690 MHz range.

5G- Device-to-Device Communication, Proposed for expansion of the Internet of Things (IoT). Uses wavelengths from 30 to 100 GHz and possibly up to 300 GHz.

3.3. The science of biological harm from non-ionizing radiation

A growing body of scientific literature documents evidence of non-thermal cellular damage from non-ionizing wireless radiation used in telecommunications. This RF EMR has been shown to cause an array of adverse effects on DNA integrity, cellular membranes, gene expression, protein synthesis, neuronal function, the blood brain barrier, melatonin production, sperm damage and immune dysfunction (Dasdag et al., 2015a; Dasdag et al., 2015a, 2015b; La Vignera et al.al., 2012; Levine et al.al., 2017). Human health effects associated with wireless radiation include infertility, neurodegenerative changes and brain cancer (Wyde, 2016; IARC, 2011) (; Sage and Carpenter, 2012; Kim et al., 2017; Kesari et al., 2011; Kesari et al., 2012a, 2012b; Zhang et al., 2016; Agarwal et al., 2011, 2008; Al-Quzwini et al., 2016; Banik, 2003; Consales, 2012; D'Andrea and Chalfin, 2000; Desai et al., 2009: Prasad et al., 2017). In addition, electrosensitivity to wireless and electrical devices is being increasingly recognized by scientists and physicians (Hojo et al., 2016; Singh and Kapoor, 2014; Belpomme et al., 2015). A biologically based standard has been recommended with a scientific benchmark to a "lowest observable effect level" for RF EMR at 0.003 uW/cm^2 (Sage and Carpenter, 2012). There is also growing evidence of harm to trees, wildlife and other biosystems (Sivani and Sudarsanam, 2013).

3.3.1. Oxidation mechanism of cellular harm

A well-studied potential mechanism of harm from radiofrequency radiation is one of cellular oxidation. Healthy biological systems require a balance of oxidation and antioxidation to fight infection and prevent disease (44, 45, 46). A review of the literature by Yakymenko et al. (2016) confirmed that in 93 of 100 studies, non-ionizing radiofrequency radiation caused a cellular stress response with excessive reactive oxygen species. He concluded, "oxidative stress induced by RFR exposure should be recognized as one of the primary mechanisms of the biological activity of this kind of radiation."

Reactive oxygen species (ROS) are a normal part of cellular processes and cell signaling. Overproduction of ROS that is not balanced with either endogenous antioxidants (superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione (GSH), melatonin), or exogenous antioxidants (Vitamin C, Vitamin E, carotenoids, polyphenols) allows the formation of free radicals that oxidize and damage DNA, proteins, membrane lipids and mitochondria. Mitochondrial DNA is more susceptible to DNA damage than nuclear DNA as it lacks histones, has a reduced ability to repair DNA, and is not protected from mitochondrial reactive oxygen species (Görlach et al., 2015). Excess ROS have been associated with exposure to toxic chemicals, pesticides and metals (Abdollahi et al., 2004; Sharma et al., 2014: Drechsel and Patel, 2008). Oxidative damage from ROS has been increasing linked to the development and/or exacerbation of a number of chronic diseases and cancer (Thannickal and Fanburg, 2000; Valko et al., 2006; Bouayed and BohnBohn, 2010; Görlach et al., 2015; Alfadda and Sallam, 2012).

3.3.2. Electrosensitivity

An increasing number of people are reporting a variety of symptoms with exposure to wireless devices and infrastructure, including headaches, insomnia, dizziness, nausea, lack of concentration, heart palpitations and depression. These are now recognized as signs of electrosensitivity or electromagnetic hypersensitivity. A personal communication and case history was recently described by Dr. Scott Eberle, a hospice physician who, after an inciting event, became electrosensitive, and discovered his continuing physical symptoms were due to wireless radiation from his computer and cell phone. (Eberle, 2014; Eberle, 2014, 2017). Reports of electrosensitivity with these nonspecific but sometimes debilitating symptoms have incidences from 1.5% of the population in Sweden to 13.3% of the population in Taiwan (Hedendahl et al., 2015).

The United States Access Board recognizes "that multiple chemical sensitivities and electromagnetic sensitivities may be considered disabilities under the ADA if they so severely impair the neurological, respiratory or other functions of an individual that it substantially limits one or more of the individual's major life activities." (ADA, 2014).

It is notable that these same symptoms were described in military personnel working near radar communications systems. A 1981 NASA report, "Electromagnetic Field Interactions: Observed Effects and Theories", described microwave sickness with a host of symptoms recorded, including headaches, eyestrain, fatigue, dizziness, disturbed sleep at night, sleepiness in daytime, moodiness, irritability, unsociability, hypochondriac reactions, feelings of fear, nervous tension, mental depression, memory impairment, pulling sensation in the scalp and brow, loss of hair, pain in muscles and heart region, breathing difficulties, and increased perspiration of extremities (NASA, 1981).

3.4. 5G technology would be a mix of microwave frequencies

The vision of the next generation of communications technology, 5G, is to have instantaneous delivery of large volumes of multimedia content over a seamless wireless connection anywhere at any time (Chávez-Santiago et al., 2015; Greenemeier, 2015). To do this, new high frequency, faster delivery bands and a wider spectral bandwidth would need to be allocated in the 6–100 GHz range. Because the shorter frequencies transmit across short distances (hundreds of meters), a dense network of cellular antennas would need to be deployed throughout cities and neighborhoods, including extensive battery backup systems.

This system proposes to be additive with a blended architecture. Plans are in the works to adopt underused licensed frequencies throughout the spectrum. It will be a network of networks, with multiple layers of frequencies, multiple devices, and multiple user interactions (Jacobfeuerborn, 2015). Small cell deployments can be used as high capacity Wi-Fi hotspots forming an outdoor mesh network with an intergenerational mix of communications networks with 5G added later. It is not a completely new technology which will be deployed, according to Chavez-Santiago et al. (2015), but a spectrum-usage combination. "5G

3.4.1. 5G deployment by 2020

The start of commercial deployment of 5G systems is expected in 2020 with rapid expansion thereafter" to support more than one thousand times today's mobile traffic volume" (Chávez-Santiago et al., 2015).

The development of this technology has been underway for several years with research and development funding from many sources. Public, private and academic partnerships have been developed to advance this initiative. There is a race for R&D with significant resources invested with expected much higher return on investment. In 2012, the University of Surrey in the United Kingdom secured £35 million in funding for the 5G Innovation Centre, 5GIC, which offers testing facilities to mobile operators developing spectrum technologies. This year they announced their first 5G digital gaming initiative (University of Surrey, 2017). 5G Americas are planning to boost development of broadband technologies in Latin America as well (FCC Letter, 2016; 5G Americas, 2017).

3.4.2. Are there downsides to 5G telecommunications technology?

Industry papers discussing 5G, talk about markets, business models, and start-ups. New white papers have focused on needs for public safety, emergency response and earthquake preparedness. How much benefit will there really be for adding all this hyper-connecting technology compared to public health and environmental consequences? A more thorough investigation is needed with all the downsides included in the analysis, including E-Waste, global climate change, toxics emissions, occupational safety, privacy, security, public safety from widespread battery backup systems, and most critically, direct human health and environmental risks. We already have 911 and satellite communications for emergencies. If this technology is adopted we will lose our critical copper landline wires that are safer, more secure, and require no battery backups. Regulations regarding cost, access and usage of this widespread internet system have yet to be determined. Health and psychosocial effects are largely absent from business discussions.

3.4.3. More antennas and more frequencies are needed for a seamless connection

5G millimeter waves (MMW) are extremely high-frequency (30–300 GHz) electromagnetic radiation. In general, the longer the wavelength the longer it travels and the farther apart broadcast stations are placed.The 5G short higher frequency millimeter wavelengths travel shorter distances (a few hundred meters) thus to achieve a seamless integrated wireless system the “small cell” antenna are proposed to be placed about every 250 m. The exact frequencies of MMW desired for the next-generation of high-speed wireless technologies are not yet configured but industry letters to the FCC seek to open all the frequencies up to 100 GHz, with some suggesting even higher frequencies (FCC Letter 5G Americas). These MMW frequencies will be mixed with current longer microwave frequencies to achieve integration of systems. At higher power densities, cell tower studies show that symptoms of electrosensitivity occur within about 300 m of a cell tower (Santini et al., 2002; Zothansiama et al., 2017). The added frequencies and close proximity of small cell antenna in this dense network are a valid concern for residents. MMW are absorbed by anything with water such as foliage thus causing attenuation of the signals and making connections with the system line of sight only (Rappaport and Deng, 2015). Millimeter waves also do not penetrate walls. This has been a problem for designers, who are still trying to figure out a solution.

3.4.4. FCC exposure limits for 5G millimeter waves

SAR levels are used for cell phones, tablets and other handheld wireless devices to determine regulatory compliance. For millimeter wavelength devices and infrastructure power density above 6 GHz (FCC) and above 10 GHz (ICNIRP) needs to be measured with power density (FCC, 1997; Wu et al., 2015a) This is due to the higher energy absorption in a shallow area that causes heating more rapidly resulting in much higher SAR levels. The FCC maximum permissible exposure (MPE) in terms of power density for frequencies between 1.5 and 100 GHz is 10 mW/cm^2 over a 30 min period (FCC, 1997; Romanenko et al., 2014). Heat generated is a concern in handheld devices for 5G but is still considered the only valid measure of harm, no biological cellular alterations are considered (Wu et al., 2015a).

3.4.5. Studies on millimeter wavelenghts

Millimeter waves (MMW) are absorbed by water in living plants, bacteria, insects and human skin with variable effects. Because of shallow penetration of MMW, the eyes and skin are of primary concern. Bacterial effects have also been examined with evidence of antibiotic resistance caused by MMW. In humans, the penetration depth of more than 90% of the transmitted power is absorbed in the epidermal and dermal layers (Wu et al., 2015a). Because the depth is so superficial, higher heating occurs more quickly with less dissipation. Many biological responses to MMW irradiation can be initiated within the skin (Isaac et al., 2012; Ziskin, 2013; Gandhi and Riazi, 1986). Systemic signaling in the skin can result in physiological effects on the nervous system, heart, and immune system mediated through neuroendocrine mechanisms (Pakhomov et al., 1998). Currently MMW is used for some high speed wireless networks (Sundeep et al., 2012) and radar sensors for car navigation (Menzel, and Moebius, 2012). Considering planned ubiquitous and continuous MMW exposure there is a need to understand any potentially negative health effects of these frequencies (National Research Council US, 1983; Liu et al., 2014; Drean et al., 2013; Mahamoud et al., 2016; Nelson et al., 2000).

3.4.5.1. Skin effects. Numerous experimental studies have shown that surface effects of low intensity MMW can be quite substantial, inducing a number of biological changes, even at non thermal levels, including cell membrane effects (Feldman et al., 2009; Ramundo-Orlando et al., 2009; Feldman et al., 2008; Millenbaugh et al., 2006; Enin et al., 1992; Ramundo-Orlando, 2012; Ziskin, 2013; Hayut et al., 2014; Ney and Abdulhalim, 2011; Chernyakov et al., 1989). There are MMW studies showing both beneficial and adverse effects, depending on frequency, modulation, power density, polarization, and exposure time (Belyaev et al., 2000). MMW has been used for many years as a non-invasive therapeutic modality in complementary medicine in many Eastern European countries for pain therapy (Taras et al., 2006) with some evidence that short term application of certain frequencies stimulate release of endogenous opioids in the skin (Ziskin, 2013). For a contrary purpose, the military are using 95 GHz MMW for non-lethal active denial systems (Gross, 2010). It appears that the 95 GHz MMW range affects the cutaneous nociceptors and act as a threatening stimulus without heating or thermal damage (LeVine, 2009). The mechanism has not been fully elucidated but researchers have proposed the sweat glands as a target. Feldman et al. (2008; 2009) demonstrated that the sweat ducts in human skin are helically shaped tubes, filled with a conductive aqueous solution. Their research indicates that sweat ducts in the skin could behave as antennas and thus respond to millimeter waves.

3.4.5.2. Ocular effects. There is particular concern for 5G applications as the eyes would also receive significant radiation especially for near field exposures. Cataracts remain the leading cause of blindness in the world, and are a societal burden due to the high incidence, cost and consequences to quality of life (CDC, 2015). NIH statistics from 2010 show there is a 17.11% overall prevalence of cataracts over age 40 (NIH NEH, 2010) and a steady rise in cataract surgeries (Gollogly et al., 2013). An eight-year study showed the total Medicare costs for cataract surgery alone was approximately 3.6 billion, which is 60% of all eye care costs (Ellwein and Urato, 2002). Well established risk factors in the development of cataracts are age, smoking, diabetes, and UVB exposure. Research is pointing towards oxidative damage as a general mechanism for age related cataracts (Spector, 1995; Ye et al., 2001; Abraham et al., 2006). Microwave radiation is also a known cause of cataracts with heat being an undisputed mechanism. The eyes lack sufficient blood flow to dissipate heat effectively. There is some evidence that repeated low level exposures to microwave radiation could cause cataracts but researchers agree that more studies are needed (Vignal et al., 2009; Carpenter and Van Ummeren, 1968; Moss et al., 1977; Foster et al., 1986; Van Umersen and Cogan, 1976; Riva et al., 2005; Ryzhov et al., 1991; Drean et al., 2013; Morgan et al., 2015).

Frey (1985) elucidates the reasons why the earlier Appleton and McCrossan study found no cataractogenesis from microwave exposure after reviewing their data. He found 3 major flaws in the study design and interpretation. These were 1) the exposed group likely included people with little or no exposure 2) control group consisted of people working with equipment known to cause eye damage 3) they never performed a statistical analysis on their data. Nevertheless, their study was held up as proof there were no harmful effects from radiofrequency radiation. Frey notes the need to critically review negative studies as this contributes to the distortion and distrust of science.

Lipman et al. (1988) noted that microwaves most commonly cause anterior and/or posterior subcapsular lenticular opacities both in experimental animals, epidemiologic studies and case reports. They indicate that cataract formation is related to the power of the microwave radiation and duration of exposure. Lipman concludes that until further definitive research is conducted on the mechanisms of injury and protective measures identified, mechanical shielding is recommended to minimize the possibility of development of radiation-induced cataracts.

Cutz (1989) in his publication "Effects of microwave radiation on the eye: The occupational health perspective", looked at occupational exposure to RF EMR noting that eye effects from microwave radiation can be thermal or non-thermal and that lens opacities can be generated experimentally in animals with relatively high intensity RF EMR (power density above 100 mW/cm^2). He states that for lower intensities cumulative exposures may cause damage. He also reported that microwaves caused degeneration of retinal nerve endings. Long term effects were not determined, pointing to the need for additional research.

Kues and Monhan (1992) at John Hopkins University, researched the effects of low-level microwave radiation on the primate eye using 1.25 and 2.45 GHz wavelengths for 4 h daily for 3 consecutive days. They identified damaging ocular effects including corneal lesions, increased vascular permeability and degeneration of photoreceptors in the retina. They found that pulsed microwave exposure produced abnormalities at lower power densities than continuous wave exposure. These were relatively short exposure periods.

Prost et al. (1994) was one of the first to study the effects of millimeter microwave radiation on the eye. He noted that microwaves of different wavelengths have been implicated in the development of cataracts. His research found that low power millimeter waves produced lens opacity in rats over a 58-day period (10 mW/cm2), indicating MMW is a predisposing factor for cataracts.

Bormusov et al. (2008) examined the non-thermal effects of high frequency radiation from cell phones and other wireless devices on lens epithelium. They found both reversible and irreversible ocular changes and notes that the effects they saw with short term exposure at low levels could translate to similar effects with cataracts over a 10–20 year period of cumulative exposure. They state "It is recommended to use cell phones from a distance to minimize exposure, thus reducing any potential harmful effects of cell phone use on the lens."

Yu and Yao (2010) reviewed literature on microwave radiation and induction of cataracts. Reports of non-thermal biologic effects of microwave radiation include alteration of cell proliferation and apoptosis, inhibition of gap junctional intercellular communication, stress response and genetic instability. They concluded that further *in vivo* studies are needed.

Shawaf (2015) reported on an acute bilateral cataract development in a healthy young radar worker due to accidental high power microwave exposure. He notes "there are also non-thermal effects of microwave energy on the eye including pressure waves and physical stretching, deformation, and tearing of the membranes of the lens cells."

In a 2014 publication in the Institute of Electrical and Electronics Engineers journal, IEEE Transactions on Microwave Theory and Techniques, Sasaki et al. (2014) reported their *in vivo* rabbit experiments for operating frequencies ranging from 24.5 to 95 GHz, measuring temperature elevation. Their studies suggest that corneal damage occurred at an incident power density of 300 mW/cm^2. They conclude that ocular heating should be the basis for safety guidelines for near field exposure. It is mentioned however that only a few experimental studies in the miilimeter wavelengths were used to determine the current exposure guideline limits.

In another IEEE publication looking at MMW health effects, Wu et al. (2015b) support current standards of safety based on heat but point out that the MMW research on biological effects is sparse relative to that of longer microwave frequencies. They advise that additional studies may be needed to examine the potential biological effects of MMW radiation in order to develop appropriate consumer guidelines, especially where antennas are located close to the body.

From the available literature it appears that microwave frequencies including MMW proposed for 5G can have non-thermal biological effects on the lens of the eye. 5G deployment will add shorter wavelengths to longer wavelengths which have not been adequately tested for long term exposure. With the expected rise of wearable ocular digital technology devices such as virtual reality for gaming, entertainment, the social sciences and healthcare, there will be significantly more exposure to microwave radiation very close to the orbit. Current safety guidelines are based on heat measurements. The paucity of current literature on ocular effects of millimeter wavelengths highlights the need for much more independent research and precaution moving forward to prevent an epidemic of ocular pathology.

3.4.5.3. Review of effects. In a very thorough review article, Pakhomov et al. (1998) looked at the biological effects of MMW. He examined dozens of studies and cites research demonstrating profound effects of MMW on all biological systems including cells, bacteria, yeast, animals and humans. Some effects were clearly thermal, however, many of the studies showed non-thermal biological effects at low intensities. Both negative and positive responses were seen depending on frequency, power, resonance and exposure time. Researchers found at times even small difference in frequencies could have very different biological effects.

Pakhomov summarized the studies and included effects on heart rate variability, teratogenicity, and bacterial growth alterations with antibiotic resistance. Chernyakov et al. (1989) induced heart rate changes in anesthetized frogs by microwave irradiation of remote skin areas. Complete denervation of the heart did not prevent the reaction. This suggested a reflex mechanism of the MMW action involving certain peripheral receptors. Potekhina et al. (1992) found certain frequencies from 53 to 78 GHz band continuous wave changed the natural heart rate variability in anesthetized rats. He showed that some frequencies had no effect (61 or 75 GH) while other frequencies (55 and 73 GHz) caused pronounced arrhythmia. There was no change in skin or whole body temperature.

One study of MMW teratogenic effects was performed in Drosophila flies by Belyaev et al. (1990). Embryos were exposed to 3 different GHz frequencies for 4–4.5 h at 0.1 mW/cm^2. He found that irradiation at 46.35 GHz, but not at 46.42 or 46.50 GHz, caused marked effects including an increase in morphological abnormalities and decreased survival. It was felt the MMW disturbed DNA-protein interactions at that particular frequency. Bulgakova et al. (1996) in studies with 14 different antibiotics showed how MMW exposure of the bacterium *S. aureus* affects its sensitivity to antibiotics with different mechanisms of action. The MMW increased or decreased antibiotic sensitivity depending on the antibiotic concentration.

Pakhomov warned that there was a possibility of significant bioeffects of millimeter wave technology at current safety standards and more study was needed. He called for replication of studies especially long term effects of MMW.

Pakhomov concluded that the effects were not necessarily linear as different individuals may react differently, there were unknown and uncontrolled factors affecting sensitivities, and electrosensitivity to millimeters may be real with 30 to 80% of test subjects able to feel low intensity millimeter wave radiation.

3.4.5.4. Immune system. Kolomytseva et al. (2002), looked at the function of peripheral blood neutrophils under whole-body exposure of healthy mice to low-intensity extremely high-frequency electromagnetic radiation (EHF EMR, 42.0 GHz, 0.15 mW/cm^2, 20 min daily). The study showed 50% suppression of phagocytic activity of neutrophils after a single exposure to MMW radiation with the authors noting a profound effect on nonspecific immunity.

Lushnikov et al. (2003) investigated cell-mediated immunity and nonspecific inflammatory response in mice exposed to low-intensity extremely high-frequency electromagnetic radiation (EHF EMR, 42.0 GHz, 0.1 mW/cm2, 20 min daily). They found that MMW radiation reduced both immune and nonspecific inflammatory responses (130). Other research by the same group corroborated an anti-inflammatory effect of MMW that appeared mediated by the immune neuro-endocrine system. This could explain some of the reported beneficial effects. Long term exposure was not mentioned.

Gapeev et al. (2003) showed for the first time that low-intensity extremely high- frequency MMH electromagnetic radiation *in vivo* causes effects on spatial organization of chromatin in cells of lymphoid organs. Chromatin is a complex of DNA and proteins that forms chromosomes within the nucleus of eukaryotic cells. He exposed mice to a single whole-body exposure for 20 min at 42.0 GHz and 0.15 mW/cm^2. He suggests that the effects were due to involvement of the neuroendocrine and central nervous systems.

3.4.5.5. Tumor suppression. Makar et al. (2005) showed that MMW irradiation at 42.2 GHz can up-regulate natural killer (NK) cell functions with short exposures. An increase in TNF-alpha was also identified. Logani et al. (2006) investigated inhibition of tumor growth transplants with short 30 min pretreatment with MMW. They found a reduction in tumor metastasis by MMWs mediated through activation of NK cells. Long term exposure was not investigated.

3.4.5.6. Gene expression. Chen et al. (2008) found upregulation of some genes in human keratinocytes with MMW exposure at low power density (1.0 mW/cm^2 millimeter).

Habauzit et al. (2014) looked at gene expression in keratinocytes with 60 GHz exposure at the upper limit of current guidelines and concluded, "In our experimental design, the high number of modified genes (665) shows that the ICNIRP current limit is probably too permissive to prevent biological response."

3.4.5.7. Bacterial antibiotic resistance. Bulgakova et al. (1996) irradiated staphylococcus cultures with different frequencies of MMW with non-thermal intensities with short exposure periods (minutes). He found changes in bacterial sensitivities developed in 5 of 14 antibiotics used in sublethal concentrations with both suppression and stimulation of growth.

Shcheglov et al. (2002) examined MMW on *E. coli* cells at various cell densities and frequencies. His work suggests that cell-to-cell communication may be involved in bacterial responses to weak EMF.

Isakhanian and Trchunian (2005) irradiated water and buffer solution with low intensity MMW and found that the irradiated water had a bactericidal effect that disappeared after repeated exposure and the buffer solution increased growth of bacteria. They concluded this was due to membranotrophic effects. Repeated irradiation reversed the bactericidal effects indicating that a compensatory mechanism was involved.

Torgomyan and Trchounian (2013) reviewed research on the mechanisms of bactericidal and antibiotic resistance after exposure to low intensity MMW. They suggest that alterations in water structure, cell membrane or the genome leading to changes in metabolic pathways could account for these effects. The importance of this research is emphasized in light of ongoing concerns about bacterial resistance to antibiotics.

Soghomonyan et al. (2016) found that MMW affected growth and antibiotic sensitivity of *E. coli* and many other bacteria via non-thermal mechanisms. This may lead to antibiotic resistance.

3.5. Data gaps need to be closed before launching 5G millimeter devices

5G technology with its diverse blend of frequencies and densely packed cell antenna network will substantially increase exposure to electromagnetic radiation. Significant data gaps exist for research into both MMW and mixed frequencies for biological effects, long term exposure and vulnerable populations (children, pregnant women, chronically ill). Considering current peer reviewed science, predictable harm to life forms within the mixed frequency mesh networks with negative consequences appears likely over time. For electrosensitive individuals, it will add to their physical symptoms and isolation, with significant reduction in non-exposed safe havens. There is an urgent need for independent studies to guide development of effective public health standards and policies.

3.6. Technology addiction: overuse and over-connection

Overuse of technology and mental health is another related but no less important issue. Physicians, social scientists and educators are concerned with the over-connection to technology, especially in children and adolescents. Psychiatrists have reported an increase in technology addiction, cyberbullying, depression, insomnia, loss of empathy and impaired social-emotional learning in their young patients. Internet game disorder has been found to have psychological and neural effects similar to other types of impulse control disorders and addictions which are both substance and non-substance-related (Chi et al., 2016; Király et al., 2017; Meng et al., 2015; Sanchez-Carbonell et al., 2008; Tamura,Tamura et al., 2017; Feng et al., 2017) Lack of outdoor play and psychological well-being for young children is also of growing concern (Xu et al., 2016). We should begin to question the supposed benefits versus the true risks of a hyper-connected society.

3.7. What is public health?

There are many definitions of public health but one succinct definition is, "Public health is what we, as a society, do collectively to assure the conditions for people to be healthy." (Upshur, 2015). Public health involves the science and art of preventing and controlling disease, promoting health, monitoring populations for health assessments, identifying causes, identifying effective interventions and assuring equity in populations and communities (APHA, 2017; CDCCDC, 2017).

Public health involves an ever widening range of topics. John R. Goldsmith, MD, MPH, a pioneer in public health, wrote a seminal article in 1997 called "From Sanitation to Cellphones: Participants and Principles Involved in Environmental Health Protection" (Goldsmith, 1997a, 1997b). This work details the history of public health over his decades working in this field. He describes four phases of public health issues: sanitation (prior to 1914), industrialization (1915–1950), emissions constraints (1951–1995) and then globalization (1996 on). He notes three common principles of public health which apply through all those phases, 1) The need for regulation by government 2) Need for a market by which protection of environmental health is economically attractive compared to alternatives and 3) Social acceptability, with cultural norms endorsing protective versus risk generating behavior.

3.7.1. Wireless technologies: a question of public health

A growing number of scientists have articulated the need to recognize that the increase in wireless technologies is a serious emerging and neglected public health threat. (Blank et al., 2015; Goldsmith, 1997a, 1997b; Sage and Carpenter, 2012). In a recent poll, public health scientists were asked what they consider to be emerging public health issues (Bernier, 2017). Responses included issues such as racism, bullying, gun violence, gang violence, adult obesity and climate change. They were also asked what defines a public health issue. The open forum identified the following criteria.

1. The health impacts are preventable and modifiable.
2. There is a high prevalence of a risk factor.
3. There is an increase in incidence and prevalence.
4. There is an economic impact.
5. There is disability, morbidity and mortality.
6. It can affect a large population.
7. A collaborative effort is needed to solve it.
8. The problem can be recognized unencumbered by lack of funding, cultural norms, or politics.

For wireless technology to be considered a public health issue in this regard there would need to be broad recognition and consensus that wireless technology could cause or contribute to diseases such as brain cancer, neurodegeneration, developmental defects, infertility, electrosensitivity and addiction. The cost and burden could then be calculated. Wireless technology could fulfill the other criteria in that there is an unprecedented high prevalence in the use of wireless devices, it can affect the population as a whole, and will require collaborative action to solve. The biggest obstacles appear to be of a cultural, economic and political nature along with a noted lack of funding in the U.S. for independent scientific research on health effects of RF EMR that is free of industry influence or bias. As with tobacco, the science was denied and doubt created until overwhelming research and evidence of harm decades later shifted the debate and protective regulations followed. Chemical companies followed tobacco with similar methods to dismiss and manipulate science that was not in their favor (Michaels, 2008).

4. Conclusion

Although 5G technology may have many unimagined uses and benefits, it is also increasingly clear that significant negative consequences to human health and ecosystems could occur if it is widely adopted. Current radiofrequncy radiation wavelengths we are exposed to appear to act as a toxin to biological systems. A moratorium on the deployment of 5G is warranted, along with development of independent health and environmental advisory boards that include independent scientists who research biological effects and exposure levels of radiofrequency radiation. Sound regulatory policy regarding current and future telecommunications initiative will require more careful assessment of risks to human health, environmental health, public safety, privacy, security and social consequences. Public health regulations need to be updated to match appropriate independent science with the adoption of biologically based exposure standards prior to further deployment of 4G or 5G technology.

Considering the current science, lack of relevant exposure standards based on known biological effects and data gaps in research, we need to reduce our exposure to RF EMR where ever technically feasible. Laws or policies which restrict the full integrity of science and the scientific community with regards to health and environmental effects of wireless technologies or other toxic exposures should be changed to enable unbiased, objective and precautionary science to drive necessary public policies and regulation. Climate change, fracking, toxic emissions and microwave radiation from wireless devices all have something in common with smoking. There is much denial and confusion about health and environmental risks, along with industry insistence for absolute proof before regulatory action occurs (Frentzel-Beyme, 1994; MichaelsMichaels, 2008). There are many lessons we have not learned with the introduction of novel substances, which later became precarious environmental pollutants by not heeding warning signs from scientists (Gee, 2009). The threats of these common pollutants continue to weigh heavily on the health and wellbeing of our nation. We now accept them as the price of progress. If we do not take precautions but wait for unquestioned proof of harm will it be too late at that point for some or all of us?

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