Review Article

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Millimeter (MM) wave and microwave frequency radiation produce deeply penetrating effects: the biology and the physics

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Abstract: Millimeter wave (MM-wave) electromagnetic fields (EMFs) are predicted to not produce penetrating effects in the body. The electric but not magnetic part of MM-EMFs are almost completely absorbed within the outer 1 mm of the body. Rodents are reported to have penetrating MM-wave impacts on the brain, the myocardium, liver, kidney and bone marrow. MM-waves produce electromagnetic sensitivity-like changes in rodent, frog and skate tissues. In humans, MM-waves have penetrating effects including impacts on the brain, producing EEG changes and other neurological/neuropsychiatric changes, increases in apparent electromagnetic hypersensitivity and produce changes on ulcers and cardiac activity. This review focuses on several issues required to understand penetrating effects of MM-waves and microwaves: 1. Electronically generated EMFs are coherent, producing much higher electrical and magnetic forces then do natural incoherent EMFs. 2. The fixed relationship between electrical and magnetic fields found in EMFs in a vacuum or highly permeable medium such as air, predicted by Maxwell's equations, breaks down in other materials. Specifically, MM-wave electrical fields are almost completely absorbed in the outer 1 mm of the body due to the high dielectric constant of biological aqueous phases. However, the magnetic fields are very highly penetrating. 3. Time-varying magnetic fields have central roles in producing highly penetrating effects. The primary mechanism of EMF action is voltage-gated calcium channel (VGCC) activation with the EMFs acting via their forces on the voltage sensor, rather than by depolarization of the plasma membrane. Two distinct mechanisms, an indirect and a direct mechanism, are consistent with and predicted by the physics, to explain penetrating MM-wave VGCC activation via the voltage sensor. Time-varying coherent magnetic fields, as predicted by the Maxwell–Faraday version of Faraday's law of induction, can put forces on ions dissolved in aqueous phases deep within the body, regenerating coherent electric fields which activate the VGCC voltage sensor. In addition, time-varying magnetic fields can directly put forces on the 20 charges in the VGCC voltage sensor. There are three very important findings here which are rarely recognized in the EMF scientific literature: coherence of electronically generated EMFs; the key role of time-varying magnetic fields in generating highly penetrating effects; the key role of both modulating and pure EMF pulses in greatly increasing very short term high level time-variation of magnetic and electric fields. It is probable that genuine safety guidelines must keep nanosecond timescale-variation of coherent electric and magnetic fields below some maximum level in order to produce genuine safety. These findings have important implications with regard to 5G radiation.

Keywords: 5G modulating pulses; coherent electronically generated EMFs; EMF pathophysiological and therapeutic effects; increased [Ca2+]i and calcium signaling; modulating pulses and biological EMF effects; penetrating effects via time-varying magnetic field penetration.

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Introduction

Electronically generated electromagnetic fields (EMFs) are highly coherent, being generated at specific frequencies, with specific vector direction, with a specific phase and specific polarity. The special physics properties of such coherent EMFs have been discussed [1–5]. Similarly, biological impacts of coherent EMFs have also been discussed [6–10]. Such coherent EMFs generate much stronger electrical forces and magnetic forces than do natural incoherent EMFs. Most but not all natural EMFs are incoherent. The much stronger forces produced by electronically generated EMFs are of great importance with regard to EMF

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causation of biological effects and also with respect to our ability to use such EMFs for wireless communication. A study where coherence is central to wireless communication is the article of Geffrin et al. [5] which discusses many examples where coherence is essential for wireless communications and also discusses how antenna design is greatly influenced by the need to maintain such coherence. The biological importance of coherence was discussed in two contexts by Panagopoulos et al. [9]. The coherence of the polarity is required for maximum force generation. In addition, the coherence of phase is also important because identical phase produces constructive interference and supra-additive effects, whereas phase shifts lead to high amounts of destructive interference and much lower effects [9]. Golant [7] discusses how coherent MM-wave EMFs may produce resonance interactions with specific biological targets. Strong electrical forces produced by coherent electronically generated EMFs are an important feature of the Fröhlich [6] theoretical model of biological activity of EMFs. While it is clear from this, that there is a substantial literature that electronically generated EMFs are coherent and that such coherence is important for their acting in wireless communication and in producing non-thermal biological effects, this literature is not widely known nor is its importance appreciated among the vast majority of scientists studying EMF effects.

EMF propagation in a vacuum or in very low dielectric constant media, such as air, is characterized by a fixed relationship between the electric field and the magnetic field, as described by Maxwell's equations [11]. However electric fields are much more susceptible to absorption than are magnetic fields by many media, producing a breakdown of that fixed relationship (Keller and Karal [2]). Because the dielectric constant of intracellular and extracellular biological aqueous phases is estimated to be about 120 [12], such differential absorption is relevant to the issue of biological effects. However, as also discussed in ref. [2], the magnetic field penetration is determined by the magnetic field permeability which in essentially all biological tissues is very high, producing very high magnetic field penetration. Strong absorption of electric fields but not magnetic fields are found with MM-wave or microwave radiation traversing biological tissues and also many other media including building materials [13–15]. Electric field absorption is a function of both the dielectric properties of materials and also of the EMF frequency, such that the electric fields of MM-wave EMFs are almost completely absorbed in the outer 1 mm of the body, as shown in ref. [13–15]. The impedance of biological tissues is also likely to have roles in limiting electric field penetration. The rapid electric field absorption in biological tissues has lead telecommunications industry-associated and other scientists to predict that MM-wave biological effects will be limited to the outer 1 mm of the body and that lower microwave frequency effects, in the 400 MHz to 5 GHz range, are suggested to be limited to the outer 1–3 cm of the body. Various definitions are used to define microwave frequency radiation. In this paper, that term refers to 400 MHz to 5 GHz radiation, the range most commonly used for wireless communication.

Other scientists such as in many articles cited in Betskii and Lebedeva [16] have found deeply penetrating effects of MM-waves in human and animal bodies, but have interpreted these as possibly caused by effects near the surface of the body indirectly producing penetrating effects. Similar views are expressed in the Pakhomov et al. [17] review as follows: On p. 393, Pakhomov et al. [17] state that "The term millimeter waves (MMW) refers to extremely high frequency (30–300 GHz) electromagnetic oscillations. Coherent oscillations of this range are virtually absent from the natural electromagnetic environment." Further down [17] continues "Indeed, MMW have been reported to produce a variety of bioeffects, *many of which are quite unexpected from radiation penetrating less than 1 mm into biological tissues*" (italics added). It can be seen from this that although Pakhomov et al. [17] are aware that these MM-waves are coherent, they fail to consider that the MM-wave magnetic fields are highly penetrating and may, therefore, produce highly penetrating effects. On p. 400 of ref. [17], states that "It is clearly understood that MMW penetration into biological tissues is rather shallow, and any primary response must occur in skin or subcutaneous structures, or at the surface of the eye." This review will discuss towards its end, two distinct probable mechanisms by which highly penetrating time-varying MM-wave magnetic fields can produce highly penetrating effects reported in ref. [16, 17] and elsewhere.

Gaiduk [18] showed that when most of the water molecules are hydrogen bonded to solutes or when such solutes otherwise greatly determine water hydrogen bonding structures, as is often the case within living cells, the electric field absorption is lowered. This may be minor part of the mechanism leading to greater penetration of effects, shown below but time varying penetrating magnetic field effects are argued here to be much more important.

Penetrating effects of MM-wave and microwave radiation

Penetrating effects of non-thermal, non-pulsed, continuous wave MM-wave exposures have been reported in a large number of studies. Zalyobokskaya [19] reported that such exposures in rodents produced pathophysiological structural, functional and biochemical changes in each of the following internal organs: the brain, the myocardium, liver, kidney and bone marrow. These are each deeper in the body that 1 mm and therefore provide evidence for deeper MM-wave effects than the industry claims is possible.

Betskii and Lebedeva [16] reviewed large numbers of studies, both human and animal studies of highly penetrating nonthermal MM-wave effects. I will concentrate here on some of the human studies cited in that paper, although animal studies such as discussed in Zalyobokskaya [19] were also reviewed. When that review [16] was published, the voltage-gated calcium channel mechanism, discussed below, was not known so that their interpretation of the various findings discussed was very different from the interpretation discussed below.

We will be discussing here MM-wave effects impacting human brain function as well as a number of other penetrating effects of MM-wave radiation. References [20–24] each show that low intensity, non-thermal non-pulsed MM-wave EMFs produce changes in the EEGs in the human brain which are a measure of the electrical activity of the brain. The citations [21–24] each also find other neurological effects in addition to EEG effects are produced such MM-wave EMFs. The shortest path from outside the body into the human brain is through the skin, skull and meninges surrounding the brain, usually circa 6–7 mm in adults.

Such findings should not be surprising for two different reasons discussed in this paragraph and the following two paragraphs. Pikov et al. [25] and also Siegel and Pikov [26] at Caltech each find that stunningly low intensities of non-pulsed MM-wave EMFs produce strong impacts on brain derived neurons. Pikov et al. [25] in their abstract state that: “The applied levels of MMW power are three orders of magnitude below the existing safe limit for human exposure of 1 mW/cm^2. Surprisingly, even at these low power levels, MMWs were able to produce considerable changes in neuronal firing rate and plasma membrane properties. At the power density approaching 1 μW/cm^2, 1 min of MMW exposure reduced the firing rate to one third of the pre-exposure level in four out of eight examined neurons. The width of the action potentials was narrowed by MMW exposure to 17% of the baseline value and the membrane input resistance decreased to 54% of the baseline value across all neurons.”

Consequently, Pikov et al. [25] are seeing large, repeated impacts on neuronal cell activity at exposure levels of 1 μW/cm^2, one one-thousandth of the normal safety guideline allowable levels. They are seeing large effects at exposure levels of 1/1,000th of allowable levels. Normally, safety guideline allowable levels are set at no more than 1% of the lowest level found to produce any effects. By that standard, safety guidelines for MM-wave radiation should be *more than* 100,000 times lower than the current safety guidelines. Siegel and Pikov [26] found effects at still lower level exposures, 300 mW/cm^2, which argues that safety levels should be *more than* 330,000 times lower than current safety guidelines. It should be noted that these are cells in culture, with no shielding from tissues above the cells, other than that produced by the culture medium. Each of the findings, discussed above, are effects produced by non-pulsed, continuous wave MM-wave EMFs, not the extraordinarily highly pulsed 5G radiation, which is predicted to have vastly stronger effects than do these non-pulsed MM-wave, continuous wave EMFs, as discussed below. The US FCC and other regulatory agencies are pushing to change safety guidelines to allow much higher exposures than currently allowed by the current safety guidelines!

There is a second reason why these MM-wave, brain-related findings are not surprising. Reference [27] cited multiple primary literature studies and also review articles which show that EEGs are influenced by low intensity, non-thermal microwave frequency EMFs and also cited many primary literature studies showing that such microwave frequency EMFs also produce widespread human neurological and neuropsychiatric effects. Reference [28] cited 15 review articles showing that such microwave frequency EMFs produce neurological/neuropsychiatric effects.

The remaining human highly penetrating MM-wave effects discussed here, from Betskii and Lebedeva review [16], are apparent therapeutic effects. There are genuine therapeutic effects produced by microwave and other frequency EMFs, so it should not be surprising to find that MM-waves can produce therapeutic effects. There are multiple studies reporting that non-thermal, non-pulsed MM-waves produce improved bone marrow function in humans [29–32]. Other therapeutic effects of MM-waves include increased healing of gastric and duodenal ulcers [33] and improved cardiac function [34, 35]. Two other types of penetrating effects documented by the Pakhomov et al. [17] review, will be discussed later in this paper.

The studies outlined in the previous paragraphs of this section, are all highly penetrating effects produced by non-thermal, non-pulsed MM-wave EMFs. 5G radiation, however, uses extraordinarily high levels of modulating pulses in order to carry extraordinarily high amounts of information per second [36]. Reference [28] cited 10 different reviews each showing that EMFs with modulating pulses produce, in most cases, much higher levels of biological effects than do non-pulsed (continuous wave) EMFs of the same average intensity. If follows that 5G may be predicted to produce very damaging highly penetrating effects because of its extraordinary level of modulating pulsation. The relationship between therapeutic effects and pathophysiological effects produced by EMFs is discussed below.

The recent publication of Kostoff et al. [37] came to similar conclusions to those stated in the previous paragraphs, that MM-waves produce highly penetrating effects: "These results reinforce the conclusion of Russell (quoted above) that *systemic results may occur from millimeter wave radiation"* (italics added). Continuing from ref. [37] "To re-emphasize, for Zalyubovskaya's experiments, the incoming signal was unmodulated carrier frequency only, and the experiment was single stressor only. Thus, the expected real-world results (when human beings are impacted, the signals are pulsed and modulated, and there is exposure to many toxic stimuli) would be far more serious and would be initiated at lower (perhaps far lower) wireless radiation power fluxes."

Much deeper effects than predicted by the industry are not limited to millimeter waves but also occur with microwave radiation. Microwave radiation, as discussed above, has been argued to produce effects limited to the outer 1–3 cm in the body. However, Hässig et al. [38, 39], in Switzerland, find that pregnant cattle grazing near a cell phone tower (also known as a mobile phone base station) produce large numbers of newborn calves with cataracts. The fetus's deep location in the mother's body should protect it from cell phone tower radiation but does not. Switzerland has safety guidelines for cell phone tower radiation that are 100 times more stringent than the U.S. or EU guidelines so that these are quite low intensity EMFs by most standards, but they produce effects very deeply in the mother's body.

The rest of this paper focuses on how such highly penetrating effects can be produced. Both the biology and the physics are essential to this discussion.

The primary mechanism of action of low intensity EMFs in producing biological effects is activation of voltage-gated calcium channels (VGCCs) via its voltage sensor

The most important type of evidence for the EMF-voltage gated calcium channel (VGCC) activation mechanism, is that effects produced by EMF exposures can be blocked or greatly lowered by calcium channel blockers, drugs that are specific for blocking voltage-gated calcium channels [VGCCs) [12, 27, 28, 40]. Five different types of calcium channel blockers have been used in these studies, each of which is thought to be highly specific for blocking VGCCs [40]. Diverse EMFs produce effects which are blocked or greatly lowered by the calcium channel blockers, ranging from millimeter wave frequencies, microwave, radiofrequencies, intermediate frequencies, extremely low frequencies (including 50 and 60 Hz), all the way down to static electric fields and even static magnetic fields [12, 28, 40]. Following EMF exposure, the exposed cells and tissues have large, rapid increases in calcium signaling [12, 27, 28, 40], produced by increases in intracellular calcium [Ca2+]i levels. This overall interpretation has been confirmed by patch-clamp studies, studies using calcium-free medium, and studies measuring [Ca2+]i levels [28]. This mechanism has been widely recognized in the scientific literature with the first publication on this [40] being cited 305 times according to the Google Scholar database, at this writing. New scientific paradigms are usually only very slowly recognized in the scientific literature such that the widespread interest in and acceptance of this mechanism is very unusual. That does not, of course, mean that everyone accepts it.

The direct target of the EMFs is the voltage-sensor, which, in the normal physiology, controls the opening of the VGCCs in response to partial depolarization across the plasma membrane. Four distinct classes of VGCCs are activated in response to low level EMF exposures, L-type, T-type, N-type and P/Q-type VGCCs [40]. Voltage-gated sodium, potassium, and chloride channels, each controlled by a similar voltage sensor are also activated by low intensity EMF exposures, although these have relatively minor roles in producing effects compared with those of VGCC-produced [Ca2+]i elevation [28]. Plant TPC channel activation via a similar voltage sensor also produce plant calcium-dependent EMF effects [41]. Each of these channels is controlled by a similar voltage-sensor, suggesting that the voltage-sensor is the direct EMF target.

The electrical forces produced by even weak electronically generated EMFs on each of the 20 positive charges in the VGCC voltage sensor are thought to be very strong due each of three distinct mechanisms, which act multiplicatively: 1. Electronically generated EMFs are highly coherent, as discussed above, being emitted with a specific frequency, in a specific vector direction, with a specific phase and specific polarity. This high-level coherence causes the electrical and magnetic forces produced by these to be vastly higher than are forces produced by incoherent natural EMFs. 2. The electrical forces on these charges in the voltage sensor are thought to be approximately 120 times higher than forces on charges in the aqueous phases of our cells and bodies, as predicted be Coulomb's law, due to the difference of the dielectric constant in the two locations [12, 28]. 3. The forces on the charges in the voltage sensor are also thought, to be approximately 3,000 times higher because of the high electrical resistance of the plasma membrane and therefore the high level of amplification of the electric field across the plasma membrane [12, 28]. This helps us to understand how VGCCs and other voltage-gated ion channels can be activated by what are considered to be very weak EMFs. The important finding here is that EMFs activate the VGCCs and other voltage-gated ion channels not via depolarization of the plasma membrane but rather via the direct forces they produce on the circa 20 charges in the voltage sensor. One puzzle discussed in ref. [40] and also below in this paper is how can static magnetic fields activate the VGCCs when physics shows that static magnetic fields cannot put forces on static electrical charges. These magnetic field effects are discussed in the next section.

How then does EMF-produced VGCC activation produce biological effects? Our best understanding of this is outlined in Figure 1 [12, 28, 40]. The main pathophysiological effects seen going to the bottom of Figure 1, are produced through excessive calcium signaling produced by [Ca2+]i elevation and by the peroxynitrite pathway, with the latter involving increases in reactive free radicals, oxidative stress, NF-kappaB activity and inflammatory cytokine levels and also mitochondrial dysfunction. There is also a pathway by which VGCC activation, acting via increased nitric oxide (NO), NO signaling and Nrf2 stimulation can produce therapeutic effects that also helps explain EMF effects. The therapeutic pathway is thought to be produced by modest [Ca2+]i elevation whereas the pathophysiological pathways are produced by higher level [Ca2+]i elevation.

MM-waves have been shown to act via activation of the VGCCs and also voltage-gated potassium channels [42–44]. Therefore it seems likely that MM-waves act via such channel activation as do lower frequency EMFs. This interpretation is confirmed by findings that MM-waves raise [Ca2+]i levels, calcium signaling and also nitric oxide (NO) [42] (compare with Figure 1). It is also confirmed by findings that MM-waves raise peroxynitrite [45] and by findings, discussed above, that MM-waves can produce similar pathophysiological effects and therapeutic effects to those produced by lower frequency EMFs. There is an additional channel that is probably activated by MM-waves acting on voltage sensors, the Ca2+-activated potassium channel as shown by Geletyuk et al. [46]. It was shown in ref. [46] using patch-clamp studies, that closed Ca2+-activated potassium channels are opened by exposures to low intensity non-pulsed MM-waves. This same channel has also been shown to be activated by both 50 Hz and microwave frequency EMFs [47]. Ca2+-activated potassium channels have been shown to be activated by a voltage sensor similar in structure to the voltage sensors discussed above acting synergistically with increases in [Ca2+]i. It follows that EMFs may act to activate Ca^{2+}-activated potassium channels via the voltage sensor in that channel and also via the VGCC voltage sensors.

Can Nrf2 activation (see Figure 1) produce the therapeutic responses reported to occur following MM-wave exposures [16], as discussed in a previous section? Garkavi et al. [48] showed that MM-waves produced antistress responses and such antistress responses have been shown to be produced by therapeutic Nrf2 elevations (see, for example [49, 50]). Consequently, it is plausible that the therapeutic mechanism outlined in Figure 1 can produce the penetrating therapeutic effects, discussed above to be found following non-pulsed MM-wave exposures.

What mechanisms produce highly penetrating effects of MM-waves?

With the electrical parts of MM-wave radiation largely absorbed in the outer 1 mm of the body, how, can we get these highly penetrating effects through impacts on the voltage sensor of the VGCCs produced by these highly coherent electronically generated EMFs?

Two explanatory mechanisms are proposed here, each as a consequence of the very highly penetrating, time-varying magnetic forces produced by the highly coherent electronically generated EMFs including MM-wave EMFs. Let's consider each these two explanatory mechanisms, one at a time.

The discussion on Maxwell's equations in Wikipedia [11] states that "The Maxwell–Faraday version of Faraday's law of induction describes *how a time varying magnetic field* creates ('induces') an electric field" (italics added). Coherent highly penetrating time-varying magnetic fields will produce strong forces on ions dissolved in the aqueous phases in our bodies, moving those ions in both the extracellular medium and also in intracellular aqueous phases and therefore regenerating a highly coherent electric field similar to but of lower intensity to the original electric field of the EMF before entering the body. The regenerated EMF can, then act to put forces on the charges of the voltage sensor thus activating the VGCCs. The

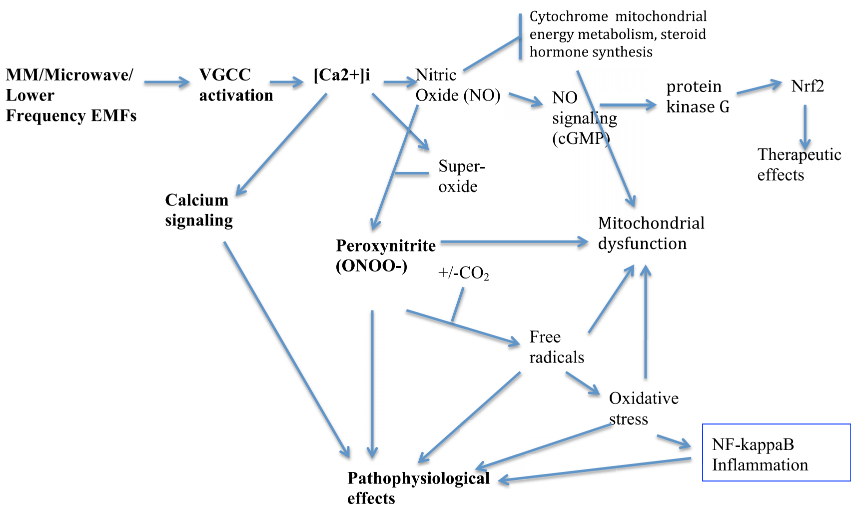

Figure 1: Diverse frequency EMFs act via activation of voltage-gated calcium channels (VGCCs) producing increased intracellular calcium [Ca2+]i. [Ca2+]i is defined as the calcium ion concentration in the cytoplasm which is distinct from the calcium concentration in the endoplasmic reticulum or the mitochondria, which are regulated separately. This leads to production of pathophysiological effects mainly via excessive calcium signaling and activation of the peroxynitrite/free radical/oxidative stress, NF-kappaB and inflammation pathway. Therapeutic effects are produced primarily via nitric oxide (NO) signaling leading to increased Nrf2 activity. Because the therapeutic pathway produces effects that are almost exactly opposite the effects produced by the peroxynitrite pathway, different EMF exposures may produce almost opposite effects. Copied from ref. [28] with permission.

physics here is essentially identical to the physics of electrical generation. In electrical generators, time-varying magnetic fields put forces on mobile electrons in copper wires, moving those mobile electrons and generating, in turn, an electrical current. In our bodies, the highly penetrating time varying magnetic fields put time-varying forces on dissolved mobile ions in aqueous phases in our bodies, generating a coherent electric field which can act on the voltage sensors to activate the VGCCs, as discussed above. A study providing support for this mechanism is the study of Deghoyan et al. [51] which found that non-thermal effects on cells in culture were produced through MM-wave irradiation of the medium surrounding these cells. This may or may not be the primary mechanism by which MM-waves produce highly penetrating effects.

There is second highly plausible mechanism by which highly penetrating magnetic fields can put forces on the charges in the voltage sensor activate voltage-gated ion channels. In ref. [40] it was shown that static magnetic fields also act, as do EMFs, via VGCC activation to produce biological effects that can be blocked with calcium channel blockers, so that the biological effects must have been produced via VGCC activation. Specifically, in Table 1 of ref. [40] and refs. [10], [12] and [24] in that paper each showed that effects produced by static magnetic fields can be blocked by calcium channel blockers, drugs specific for blocking VGCCs. Consequently, static magnetic fields produce effects via VGCC activation. That conclusion has been confirmed by the findings from patch-clamp studies, showing that static magnetic fields produced VGCC activation and also activation of voltage-gated sodium channels [52]. Those findings that static magnetic fields can act via the voltage sensor to activate VGCCs and apparently other voltage-gated ion channels created a puzzle that was discussed in ref. [40]. That puzzle is that static magnetic fields do not produce forces on static electrically charged objects. The answer to that puzzle, as discussed in ref. [40], is that the plasma membranes of cells are constantly moving and therefore the voltage sensors of the VGCCs located in the plasma membrane are also moving, so that static magnetic fields can produce time-varying forces on the charges of the VGCC voltage-sensor. These findings clearly raise the possibility that the highly penetrating time-varying magnetic fields derived from MM-wave or other frequency EMFs, including the extraordinarily high densities of modulating pulses of 5G, can have very high activity when acting directly on the 20 positive charges in the voltage sensor of the VGCCs to activate the VGCCs.

Both modulating EMF pulses and pure EMF pulses can act via each of the two mechanisms discussed here to produce large, very short term, penetrating changes in the forces on electrical charges including the voltage gated ion channel voltage sensor charges. Modulating and pure pulses inevitably produce vastly greater maximum time-variation and are, therefore, predicted to produce vastly greater maximum forces on the voltage sensor charges.

Because each of the two mechanisms proposed in this section for the generation of penetrating effects are dependent upon time-varying magnetic fields, together they provide a new understanding of the great importance of both modulating and pure pulsation in producing high level EMF effects.

Pakhomov et al. [17] reviewed findings with regard to non-pulsed MM-Waves: cardiac effects and electromagnetic hypersensitivity (EHS)

There are important findings on both animal cardiac effects and on animal tissue and human EHS-like effects produced by non-pulsed MM-wave exposures that were reviewed in Pakhomov et al. [17]. These are discussed here, in contrast, other MM-wave studies including those reviewed by Zalyobokskaya [19] and by Betskii and Lebedeva [16] which were discussed much earlier.

There are two important reasons for the author choosing to discuss the Pakhomov et al. [17] review on cardiac effects and also EHS-like effects here, as opposed to much earlier. Each of these require comparing animal studies with human studies. When highly penetrating MM-wave magnetic fields produce highly penetrating effects in animals and in humans, the difference in body size between humans and rodents is of little importance in predicting effects. A second reason for discussing these parts of ref. [17] here, is that the VGCC activation mechanism discussed above is predicted to be central to our understanding of both cardiac effects and EHS.

Chernyakov et al. [53], as discussed on p. 399 of ref. [17], reported on 990 experiments where very low intensity MM-wave EMFs changed the membrane function of the pacemaker cells of the sinoatrial node of the frog heart. In most cases, there was an almost instantaneous (less than 2 s) decrease in the interspike interval of these cells which in an intact heart would produce tachycardia. These occurred with intensity ranges of 20–500 $\mu W/cm^2$ and were, therefore, clearly non-thermal effects. Furthermore, as discussed on p.400 of ref. [17], Chernyakov et al. [53] showed that very low intensity MM-wave EMFs could produce changes in heart rate in anesthetized frogs, including both tachycardia (increase heartbeat) and bradycardia (slow heartbeat) and also arrhythmias. These also occurred when the hearts had been completely denervated although the severity of these changes decreased with denervation. The studies in this paragraph show that low intensity MM-wave EMFs produce direct effects on the membrane activity of the pacemaker cells in the sinoatrial node of the frog heart, influencing the heartbeat, but that the responsiveness of these cells can be influenced by neurological activity.

Other important cardiac studies of low intensity MM-waves were reported by Potekhina et al. [54] in the rat. They [54] showed that MM-waves produced changes in heartbeat including arrhythmias, tachycardia and bradycardia. Longer term (circa 3 h) exposures produced large numbers of animals who died of apparent sudden cardiac death. It is the author's opinion that most if not all of these EMF cardiac effects are produced by the direct impacts of diverse EMFs impacting the pacemaker cells in the sinoatrial node of the heart. One additional set of observations supporting that view are the findings of Liu et al. [55] showing that pulsed microwave EMFs produce heart failure-like changes in the sinoatrial node of the heart. The reason the pacemaker cells of the sinoatrial node of the heart may be particularly sensitive to EMFs is because they contain particularly high densities of T-type VGCCs, with both T-type and L-type VGCCs having essential roles in producing the pace making activity [56, 57]. These findings suggest that penetrating EMF effects can produce commonly observed cardiac effects via direct impacts on the pacemaker cells in the sinoatrial node of the heart.

Pakhomov et al. [17] also reviewed findings showing that non-pulsed MM-wave EMF exposures produce EHS-like effects in animal nerve tissue, and in humans. EHS is characterized by long term sensitivity responses to electromagnetic or electric fields [17] describes three studies where non-pulsed MM-wave exposures produced fairly long-term sensitivities in animal tissues and three additional studies of long term neurological/neuropsychiatric sensitivity in humans.

Burachas and Mascoliunas [58] described changes in the compound action potential (CAP) in the frog sciatic nerve following MM-wave exposures. They found that "CAP decreased exponentially and fell 10-fold within 50–110 min of exposure at 77.7 GHz, 10 mW/cm^2. CAP restored entirely soon after exposure, but the nerve became far more sensitive to MMW. CAP suppression due to the next exposures became increasingly steep and finally took only 10–15 min. This sensitized state persisted for at least 16 h" CAP is a measure of the overall electrical activity of the nerve. These findings may be interpreted in terms of MM-wave EMF exposures producing long-term EHS-like sensitivities in the frog sciatic nerve.

A second study by Chernyakov et al. [53] also reported sensitivity changes using a different frog nerve and also different MM-wave exposure protocols. "The exposures lasted 2–3 h, either with a regular frequency change of 1 GHz every 8–9 min or with a random frequency change every 1–4 min (53–78 GHz band, 0.1–0.2 mW/cm^2). The latter regimen induced an abrupt CAP 'rearrangement' in 11 of 12 exposed preparations: the position, magnitude and polarity of the CAP peaks (the initial CAP was polyphasic) drastically changed in an unforeseeable manner. The other exposure regimen altered the CAP peaks components in 30–40 min"

Akoev et al. [59] found EHS-like effects following low intensity MM-wave exposures on the activity of electroreceptors of skates (the article cited here is an English language study, published in an international journal that appears to be similar or identical to the Russian language article cited in ref. [17]). "When a power intensity of 1–5 mW/cm^2 was used at a distance of 1–20 mm from the duct opening only excitatory responses were observed in receptors with electrical thresholds of 4–20 nA", p. 15 in ref. [59]. Reference [59] states further (p. 17) "It is of interest that at low EMR intensity, the electroreceptors (have) prolonged excitatory responses which differ from responses to the d.c. electrical stimuli (where) the ampullae of Lorenzini completely adapt within a few minutes. Thus it is the long-lasting slow adapting excitatory response that may reflect the peculiarity of the low-intensity millimeter-wave EMR effect on biological tissues." These results show that low intensity MM-wave EMFs produce long-term hypersensitivity of the electroreceptors. There are similar electroreceptors in sharks, skates and rays and given that the target producing hypersensitivity here is that receptor, it is important to identify the identity of electroreceptor. Bellono et al. [60] showed that the electroreceptor is the VGCC Ca(V)1.3. Other studies implicate excessive [Ca2+]i in electroreception and VGCC activation was also implicated in the Zhang et al. [61] study of the skate electrosensor. We have, therefore, VGCCs implicated as the direct EMF target involved in producing EHS-like responses.

Is there other evidence implicated excessive VGCC sensitivity in producing EHS? One such study was published by Dr. Cornelia Waldmann-Selsam [62]. She studied an EHS patient who showed high sensitivity to extremely low intensity EMFs and who also had a profound parathyroid deficiency. This patient showed very large rapid drops in extracellular Ca^{2+} concentration, including in the blood plasma, following extremely low intensity EMF exposure. Because the only possible mechanism that can produce such a large rapid drop in extracellular Ca^{2+} concentration is a large influx of Ca^{2+} ions into cells of our bodies, this argues strongly for EHS producing large increases in activity of one or more calcium channels in the plasma membranes of cells. Because VGCC activation is known to be the major mechanism of EMFs, all of these findings argue that the VGCCs in EHS become hypersensitive to EMF activation.

The parathyroid deficiency of this patient [62] is of great importance because in people with normal parathyroid function, large drops in extracellular calcium levels produce a rapid increase in parathyroid hormone secretion, which mobilizes calcium from the bones to help restore normal extracellular calcium levels, thus making drops of extracellular Ca^{2+} concentrations in exposed EHS patients with normal parathyroid function more difficult to document. However, these considerations suggest a simple clinical test for EHS patients. Such patients should have large increases in parathyroid hormone following low intensity EMF exposures to which they report sensitivity, whereas normal people should not show such large increases to the same exposures. Because parathyroid hormone can be measured by clinical testing laboratories, this prediction can be easily tested and possibly used as a simple, inexpensive test of EHS.

A fourth MM-wave animal study, discussed above in this section, also suggests possible EHS-like effects in animals. This is the Potekhina et al. [54] study in the rat which found that non-pulsed MM-wave exposures for 3 h or more started to produce apparent sudden cardiac death in these exposed rats. These findings suggest cumulative effects of EMF exposure. However, their relevance to EHS must be viewed as more questionable than are the three studies discussed more immediately above, because there were no measurements which demonstrated that exposures produced increased sensitivity following MM-wave exposures in Potekhina et al. [54].

Three human studies, cited in ref. [17] each showed apparent EHS effects following low intensity non-pulsed MM-wave exposures, including neurological/neuropsychiatric sensitivities [21, 63, 64]. The sensitivities shown in each are brain-related neurological/neuropsychiatric sensitivities that are commonly reported in EHS.

EHS causation by EMF exposures is not only documented by the studies cited above. They are also documented by the largest occupational exposures ever performed, as shown in the Hecht review of such exposures [65]. Reference [65] also documents EMF causation of neurological/neuropsychiatric effects and cardiac effects.

In addition the much earlier US Government (NASA) document [66] also documents EMF occupational exposure causation of neurological/neuropsychiatric effect and cardiac effects [28] lists 15 different published reviews each of which provide substantial bodies of evidence that neurological/neuropsychiatric effects are caused by low-intensity, non-thermal EMF exposures. Lamech [67] showed that smart meter radiation exposure was associated with large increases in EHS, neurological/neuropsychiatric effects and cardiac effects and similar findings were reported in the Conrad study of smart meter radiation.

Four reviews on EHS each report that among the most common sensitivities in EHS patients are neurological/neuropsychiatric sensitivity and cardiac sensitivity [65, 68–70].

It follows from the findings discussed in this section, that EMFs with substantial impacts on our bodies will produce many cases of EHS with the consequent sensitivity responses often including neurological/neuropsychiatric effects and cardiac effects. The next question to be considered here is whether 5G radiation is likely to be among the EMFs that may produce substantial impacts.

Earlier in this paper we discussed two important findings that are important for assessing the probable impacts of 5G radiation. 5G radiation, however, uses extraordinarily high levels of modulating pulses in order to carry extraordinarily high amounts of information per second [36]. Reference [28] cited 10 different reviews each showing that EMFs with modulating pulses produce, in most cases, much higher levels of biological effects than do non-pulsed (continuous wave) EMFs of the same average intensity. If follows that 5G may be predicted to produce very damaging highly penetrating effects because of its extraordinary level of modulating pulsations.

Is there any evidence that 5G radiation produces high human impacts including EHS, neurological/neuropsychiatric effects and cardiac effects?

There has been no biological safety testing of highly pulsed 5G radiation despite calls from many scientists for such testing before any 5G rollout should occur. There have also been no scientific studies of 5G radiation effects after any 5G rollouts, to my knowledge. Consequently, the only evidence we have is from reports of 5G effects in the media. These reports are not, of course, scientific studies but rather are derived from what may be viewed as questionable observations. Nevertheless, due to the lack of any other 5G information, it is important to look at what little information we do have.

Reference [71] is a German news article about protests of German physicians in Stuttgart Germany following a 5G rollout. The physicians report seeing substantial apparent effects on their patients including neurological/neuropsychiatric effects, cardiac effects and EHS. These observations can be seen to be similar to the predicted 5G effects in the previous section. German physicians may be more aware of EHS than are physicians in other countries because the European environmental medicine organization, EUROPAEM, has been headquartered in Germany for many years – [69] is a EUROPAEM-related paper.

There are also reports of neurological/neuropsychiatric effects, cardiac effects and possibly also EHS in Switzerland following 5G rollout in parts of that country [72–74]. These reports may be somewhat less reliable than those from Stuttgart because they come from lay people.

There was much concern about three suicides over an 11 day period of emergency medical technicians working in the first 5G ambulance [75]. This occurred in Coventry, UK. The idea was that 5G could be used to transmit much medical information from the hospital to the ambulance and could also be used to transmit much electronic patient information from the ambulance to the hospital. The first EMT suicide occurred approximately two weeks after the EMTs started working in the 5G ambulance. Among the more common neuropsychiatric effects produced in humans by EMF exposures are depression and anxiety [27], both of which when severe can cause suicide. It is possible that EHS may play a role in the approximate two week time period between the beginning of service of the 5G ambulance and the first suicide. Development of progressively more severe EHS over that two week period may be predicted to produce progressively more severe depression and anxiety.

Again, these are not scientific studies but given the lack of any contrary information, they need to be taken seriously and should be the subject of serious scientific study rather than massive rollout of untested and possibly very dangerous 5G systems. One thing that should be pointed out is that any initial effects on rollout of 5G, are likely to be dwarfed by effects of any full-fledged 5G system communicating with billions of devices on the 'internet of things." Of course, the effects of such massive amounts of pulsed EMF communication may be further amplified through the action of EHS in the victims.

Search strategies

Articles on important physical or biological properties of coherent electronically generated EMFs were found using two search strategies: The EMF Portal database was searched using coherent or coherence. The Web of Science database and Google Scholar were each searched using electromagnetic fields and coherent.

Reviews on biological including human effects of millimeter waves were searched for in the EMF Portal database searching with the words millimeter waves and limiting responses to review articles. Similarly, reviews were searched in the EMF Portal database using EHS to identify EHS reviews.

The work on EMFs acting primarily via the voltage sensor to activate VGCCs is limited to my own work where only highly cited peer-reviewed articles were cited.

Two specific questions were answered as follows

When it was shown that millimeter wave exposures produced increased sensitivity of the skate electroreceptor, it was important to determine whether the electroreceptor is a VGCC, the most important direct target of EMFs. A Web of Science search using electroreceptor and voltage calcium channel found two studies each showing that the electroreceptor is a VGCC.

It was shown that millimeter waves act directly on the pacemaker cells of the sinoatrial node of the heart to change the beat frequency. It was important to determine whether microwave frequency radiation also target such cells in the sinoatrial node. A search of the EMF Portal database limited to radiation over 1 MHz for studies on sinoatrial node found a study showing that repeated or prolonged exposures produced heart failure-like changes in the sinoatrial node of the rat heart.

Two of the Russian language articles are available as CIA English translations, as shown in the citation list. All other foreign language documents cited where suitable PDFs of the original documents were available were translated into English using Google Translate.

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