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

Martin L. Pall, Professor Emeritus of Biochemistry and Basic Medical Sciences,
Washington State University
(home address) 638 NE 41st Ave., Portland OR 97232-3312 USA
martin_pall@wsu.edu

Key words:

Coherent electronically generated EMFs
Increased [Ca2+]i and calcium signaling
Penetrating effects via magnetic field penetration
Modulating pulses and biological EMF effects
5G modulating pulses
Analysis of mechanism via both physics and biology
EMF pathophysiological and therapeutic effects

Abstract:

Purpose: The author and Kostoff et al, have found strong empirical evidence that MM wave EMFs produce highly penetrating effects in humans and animals and microwave frequency EMFs also produce highly penetrating effects. This minireview describes this evidence and the probable biology and physics behind the mechanisms producing such penetrating effects.
Conclusions: Electronically generated EMFs are highly coherent in frequency, vector direction, phase and polarity, such that they produce much stronger electrical and magnetic forces than do most natural EMFs which are incoherent While the electrical parts of coherent EMFs may be largely absorbed in the outer parts of the body, the magnetic parts are very highly penetrating. Those magnetic fields put forces on dissolved ions, moving them and regenerating coherent electrical fields deeply within the body. Those coherent electrical fields put forces on the voltage sensor of the voltage-gated calcium channels (VGCCs), the main target of diverse EMFs, opening the channels and producing excessive intracellular calcium (Ca2+)i and downstream pathophysiological effects, leading to diverse biomedical impacts. In addition, time varying magnetic fields can

directly put forces on the charges in the VGCC voltage sensor, activating the VGCCs. Highly pulsed 5G radiation health impacts may be especially high due to both penetration mechanisms.

No outside funding was used for this study.

The author declares no conflict of interest.

ORCID #: 0000-0002-8784-8287

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 properties of such coherence has been discussed in several different contexts with regard to the physics of such EMFs (Boivin and Wolf, 1965; Keller and Karal, 1966; Wolf E, 2003, Tervo et al, 2003; Geffrin et al, 2012) and the biology of coherent EMFs (Fröhlich 1968; Golant, 1989; Eichwald and Kaiser, 1995; Panagopoulos et al, 2015, Preto, 2016;). Such coherent EMFs generate much stronger electrical forces and magnetic forces than do natural incoherent EMF. Most but not all natural EMFs re incoherent . The much stronger forces produced by electronically generated EMFs are of great importance with regard to EMF causation of biological effects and with respect to our ability to use such EMFs for wireless communication. An example where coherence is central to wireless communication in the article of Geffrin et al 2012 discusses how antenna design is greatly influenced by the need to maintain coherence. The importance of coherence was discussed in two contexts by Panagopoulos et al (). 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. Golant 1989 discusses how coherent MM wave EMFs may produce resonance interactions with specific biological targets.

EMF propagation in a vacuum or in very low dielectric constant media, such as air, is characterized by a fixed relationship between the electrical field and the magnetic field, as described by Maxwell's equations. However electrical fields are much more susceptible to absorption than are magnetic fields by many media, producing a breakdown of that fixed relationship

(Keller and Karal, 2004). Because the dielectric constant of intracellular and extracellular aqueous phases are estimated to be about 120 (Pall, 2015), such differential absorption is relevant to the issue of biological effects. Strong absorption of electrical fields but not magnetic fields are found with MM-wave or microwave radiation traversing biological tissues and also many other media including building materials (Wei et al, 2014; Betskii and Yaremko, 1998; Betskii and Putvinskii, 1986). Electrical field absorption is a function of both the dielectric properties of materials and also of the EMF frequency, such that the electrical fields of MM-wave EMFs are almost completely absorbed in the outer 1 mm of the body because of the high dielectric constant of the aqueous phases in our bodies. The rapid electrical field absorption in biological tissues has lead telecommunications industry-associated 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 would be limited to the outer 2 to 3 cm of the body. Other scientists such as in many articles cited in Betskii and Lebedeva, 2004 have found deeply penetrating effects of MM-waves in human and animal bodies, but have interpreted these as probably caused by effects near the surface of the body indirectly producing penetrating effects. Gaiduk 1991 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 electrical field absorption is lowered. This may be very minor part of the mechanism leading to greater penetration of effects, shown below. It will be argued below that two additional mechanisms involving the highly penetrating time-varying magnetic fields may be much more important in producing highly penetrating effects.

Penetrating Effects of MM-wave and Microwave Radiation

Penetrating effects of nonthermal, unpulsed MM-wave exposures have been reported in a large number of studies. Zalyobokskaya 1977 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 & Lebedeva 2004 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 1977 were also reviewed. When that review 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. Lebedeva, 1993, 1994, 1998a and 1998b and also Lebedeva and Sulimov 1994 each show that low intensity, non-thermal unpulsed MM-wave EMFs produce changes in the EEGs in the human brain which are a measure of the electrical activity of the brain. The last three of these citations, Lebedeva 1998a and 1998b and Lebedeva and Sulimova 1994 each also find other neurological effects of such MM-wave EMFs. Such findings should not be surprising for two different reasons. Pikov et al 2010 and also Siegel and Pikov 2010 at Caltech each find that stunningly low intensities of unpulsed MM-wave EMFs produce strong impacts on brain derived neurons. Pikov et al, 2010 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."

So first of all, Pikov et al, 2010 are seeing large, consistent impacts on neuronal cell activity at exposure levels of 1 μW/cm^2, one one-thousandth of the normal safety guideline allowable levels. So in other words, they are seeing large effects at exposure levels of 1/1000th of allowable levels. Normally, safety guidelines allowable levels are set at less 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, 2010 found effects at still lower level exposures, 300 nw/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, although there is some culture medium above those neuronal cells. And these findings are for unpulsed MM-wave EMFs, not to the extraordinarily highly pulsed 5G radiation, which is predicted to have vastly stronger effects than do these unpulsed MM-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. Pall 2016a 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 neurological and neuropsychiatric effects. Pall 2018 cited many review articles showing that such microwave frequency EMFs produce neurological/neuropsychiatric effects.

The remaining human highly penetrating MM-wave effects discussed here, from Betskii & Lebedeva 2004, 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, unpulsed MM-waves produce improved bone marrow function in humans (Pletnev, 1991; Pletnev et al, 1991; Sevast'yanova, 1983; Sevast'yanova et al, 1985). Other therapeutic effects of MM-waves include increased healing of gastric and duodenal ulcers (Poslavskii 1991) and improved cardiac function (Lebedeva 2000; Lyusov et al, 1995).

The studies outlined in the previous paragraphs of this section, are all highly penetrating effects produced by non-thermal, unpulsed MM-wave EMFs. 5G radiation, however, uses extraordinarily high levels of modulating pulses in order to carry extraordinarily high amounts of information per second (Wu et al, 2015). Pall, 2018 cited 10 different reviews each showing that EMFs with modulating pulses produce, in most cases, much higher levels of biological effects than do unpulsed (continuous wave) EMFs of the same average intensity. If follows that 5G may be predicted to produce penetrating effects with very damaging effects because of its extraordinary pulsation. The relationship between therapeutic effects and pathophysiological effects produced by EMFs is discussed below.

The recent publication of Kostoff et al, 2020 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.*** 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 has been argued to produce effects limited to the outer two to three centimeters in the body. However, Hässig et al, 2009 & 2012, 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) (Pall, 2013; 2015; 2016a; 2018). 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 (Pall, 2013). 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 electrical fields and even static magnetic fields (Pall 2013; 2015; 2018 and see below). Following EMF exposure, the exposed cells and tissues have large, rapid increases in calcium signaling Pall 2013, 2015; 2016a; 2018), 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 (Pall, 2018). This mechanism has been widely recognized in the scientific literature with the first publication on this (Pall, 2013) being cited 273 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 (Pall, 2013). Voltage-gated sodium, potassium, and chloride channels 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 (Pall, 2018). Plant TPC channel activation via a similar voltage sensor also produces plant calcium-dependent EMF effects (Pall 2016b). Each of these channels is controlled by a similar voltage-sensor, suggesting that the voltage-sensor is the direct EMF target. Panagopoulos et al, 2000 first suggested that voltage-gated ion channels might be a main target of EMFs, based on a biophysical model quite different from the mechanism discussed in the next paragraph.

The 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 for each of three distinct reasons, 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 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, due to the dielectric constant of the VGCC charge environment acting via Coulomb's law (Pall, 2015 & 2018). 3. The forces on the charges in the voltage sensor are also thought, to be approximately 3000 times higher because of the high electrical resistance of the plasma membrane and therefore the high level of amplification of the electrical field across the plasma membrane (Pall, 2015 & 2018). 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. One puzzle discussed in (Pall, 2013) 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 Fig. 1. The main pathophysiological effects seen going to the bottom of Fig. 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 effect. 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 (Titushkin et al 2009; Alekseev and Ziskin, 1999; Li et al 2013), so 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 NO (Titushkin et al, 2009). It is also confirmed by findings that MM-waves raise peroxynitrite (Sypniewska et al, 2010) and by findings, discussed above, that MM-waves can produce similar pathophysiological effects and therapeutic effects to those produced by lower frequency EMFs.

Can Nrf2 activation produce the therapeutic responses reported to occur following MM-wave exposures, as discussed in the previous section? Garkavi et al 1998 showed that MM-waves produced antistress responses and such antistress responses have been shown to be produced by Nrf2 elevations (see, for example Trougakos, 2019; Gao et al, 2016). Consequently it is quite reasonable that the therapeutic mechanism outlined in Fig. 1 can produce the penetrating therapeutic effects found following unpulsed MM-wave exposures.

It is thought that modest increases in [Ca2+]i produce therapeutic effects but larger increases activate the two pathways producing pathophysiological effects.

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 explanations both involve the very highly penetrating, strong magnetic forces produced by the highly coherent electronically generated EMFs including MM-wave EMFs. Let's consider these two, one at a time.

The discussion on Maxwell's equations in Wikipedia states that "The Maxwell–Faraday version of Faraday's law of induction describes how a time varying magnetic field creates ('induces') an electric field. In integral form, it states that the work per unit charge required to move a charge around a closed loop equals the rate of change of the magnetic flux through the enclosed surface." 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 electrical field which can, then act to put forces on the charges of the voltage sensor and activating the VGCCs. The 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 electrical field which can act on the voltage sensors of the VGCCs to activate the VGCCs, as discussed above. A study providing some support for this mechanism is the study of Deghoyan et al (2012) which found that nonthermal effects on *in vitro* cells were produced through MM-wave irradiation of the medium surrounding these cells. I believe that this is likely to be the primary mechanism by which MM-waves produce highly penetrating effects.

However there is another possible mechanism by which highly penetrating magnetic fields can activate the voltage sensor. In Pall, 2013 it was shown that static magnetic fields also act 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, Pall, 2013, refs # 10, 12 and 24 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 (Lu et al, 2015). 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 Pall, 2013. That puzzle is that static magnetic fields do not produce forces on static electrically charged objects. The answer to that puzzle, also discussed in Pall, 2013, is that the plasma membranes of cells are constantly moving, such that because the voltage sensor of the VGCCs located in the plasma membrane, static magnetic fields can produce forces on the charges of the VGCC voltage-sensor because it is constantly moving. These findings clearly raise the possibility that the highly penetrating time varying magnetic fields derived from MM-wave 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 produce large, very short term, penetrating increases in the forces on electrical charges including the voltage gated ion channel voltage sensors charges. Because both of these mechanisms for the generation of penetrating effects are dependent upon time varying magnetic fields, together they provide a new understanding of the great importance of pulsation in producing EMF effects.

Summary of Findings with Implications Regarding 5G

1. Electronically generated EMFs are coherent, such that they produce much stronger electrical and magnetic forces.

2. The fixed relationship between electrical and magnetic fields, described by Maxwell's equations in a vacuum breaks down in bodily tissues and other materials, such that EMF magnetic fields are vastly more penetrating than are electrical fields. MM-waves have their electrical fields absorbed readily in body tissues but magnetic fields are vastly more penetrating.
3. MM-waves have been shown to produce highly penetrating effects in humans and in animals conflicting with industry predictions.
4. MM-waves have been shown to produce powerful effects on neurons, suggesting that safety guidelines allow exposures at least 100,000 to over 300,000 times too high.
5. Both modulating pulses and pure pulses make EMFs, in most cases, much more biologically active than are unpulsed EMFs of the same average intensity. This predicts that the extraordinarily high levels of modulating pulses in 5G radiation make it likely that 5G will be vastly more biologically active than are unpulsed MM-wave EMFs of the same average intensity.
6. MM-wave and lower frequency EMFs act primarily by interacting with the voltage sensor and activating VGCCs, thus increasing intracellular calcium levels.
7. Two distinct mechanisms are discussed by which very highly penetrating effects can be produced by magnetic fields of MM-waves or microwaves. Both of these involve well characterized physics, impacting the VGCC voltage sensor and leading to VGCC activation. Together, these two mechanisms provide a new understanding of the importance of pulsation in producing penetrating biological effects.

These findings suggest that 5G radiation may produce health impacts at levels hundreds of thousands or even millions of times lower than the lowest exposures not allowed under the safety guidelines. While there have been news reports of such possible 5G effects in Europe, no one is systematically collecting information of 5G health impacts in humans or in animals.

Citations:

Alekseev SI, Ziskin MC. 1999 Effects of millimeter waves on ionic currents of Lymnaea neurons. Bioelectromagnetics 20: 24-33.

Boivin A, Wolf, E. 1965 Electromagnetic field in the neighborhood of the focus of a coherent beam.

Betskii OV & Lebedeva NN. 2004 Low-intensity millimeter waves in biology and medicine. In:, Marcel Decker, New York, pp. 30-61. https://gabrielecripezzi.com/wp-content/uploads/2019/06/d75d92b7fb8f4d13ae5461e26afa62e87e60.pdf (Accessed May 10, 2020)
Betskii OV & Putvinskii AV, 1986.
Biological action of low intensity millimeter wave band radiation. Izvestiya VUZ Radioelektronika 29:4-10. Released in English translation: CIA-RPD-00792R00010070001-9
Betskii OV, Yaremko YG. 1998 Skin and electromagnetic fields. Millimetrovye Volny v Biologii I Meditsine 1:2-14. (in Russian)
Boivin A, Wolf E. 1965. Electromagnetic field in the neighborhood of the focus of a coherent beam. Phys Rev 138: B1561.
Deghoyan A, Hequimayan A, Nikoghosyan A, Dadasyan E, Ayrapetyan S. 2012. Cell bathing medium as a cellular target for millimeter waves. Electromagn Biol Med 31:132-142.
Eichwald C, Kaiser F. 1995 Model for external influences on cellular signal transduction pathways including cytosolic calcium oscillations. Bioelectromagnetics 16:75-85.
Gao B, Doan A, Hybertson BM. 2014. The clinical potential of influencing Nrf2 signaling in degenerative and immunological disorders. Clin Pharmacol 2014 Feb 3;6:19-34. doi: 10.2147/CPAA.S35078.
Garkavi LK, Kvakina EB, Kuz'menko TS. 1998 Antistress reactions and activation therapy. Moscow: Imedis 617, 1998 (in Russian).
JM Geffrin, B García-Cámara, R Gómez-Medina, Albella P, Froufe-Pe´rez LS, Eyraud C, Litman A, Vaillon R, Gonza´lez F, Nieto-Vesperinas JJ. Sa´enz JJ. Moreno F. 2012. Magnetic and electric coherence in forward- and back-scattered electromagnetic waves by a single dielectric subwavelength sphere. Nature Com 3:1-7.
Golant MB. 1989 Problem of the resonance action of coherent electromagnetic radiations of the millimeter wave range on living organisms. Biophysics 34:370-382. English translation of Biofizika 1989; 34;339-348.
Fröhlich H. 1968 Long-range coherence and energy storage in biological systems. Int J Quant Chem 2:641-652.
Gaiduk VI. 1991 Water, Radiation and Life, Moscow: Znanie, Ser. Fizika, 64 p.
Gao M, Liu, Y, Chen Y, Yin C, Liu, J-JCS 2016 miR-214 protects erythroid cells against oxidative stress by targeting ATF4 and EZH2. Free Rad Biol Med 92:39-49. doi.org/10.1016/j.freeradbiomed.2016.01.005
Hässig M, Jud F, Naegeli H, Kupper J, Spiess BM. 2009 Prevalence of nuclear cataract in Swiss veal calves and its possible association with mobile telephone antenna base stations. Schweiz Arch Tierheilkd 151:471-478.
Hässig M, Jud F, Spiess B. 2012 [Increased occurrence of nuclear cataract in the calf after erection of a mobile phone base station]. Schweiz Arch Tierheilkd 154:82-86. (in German)

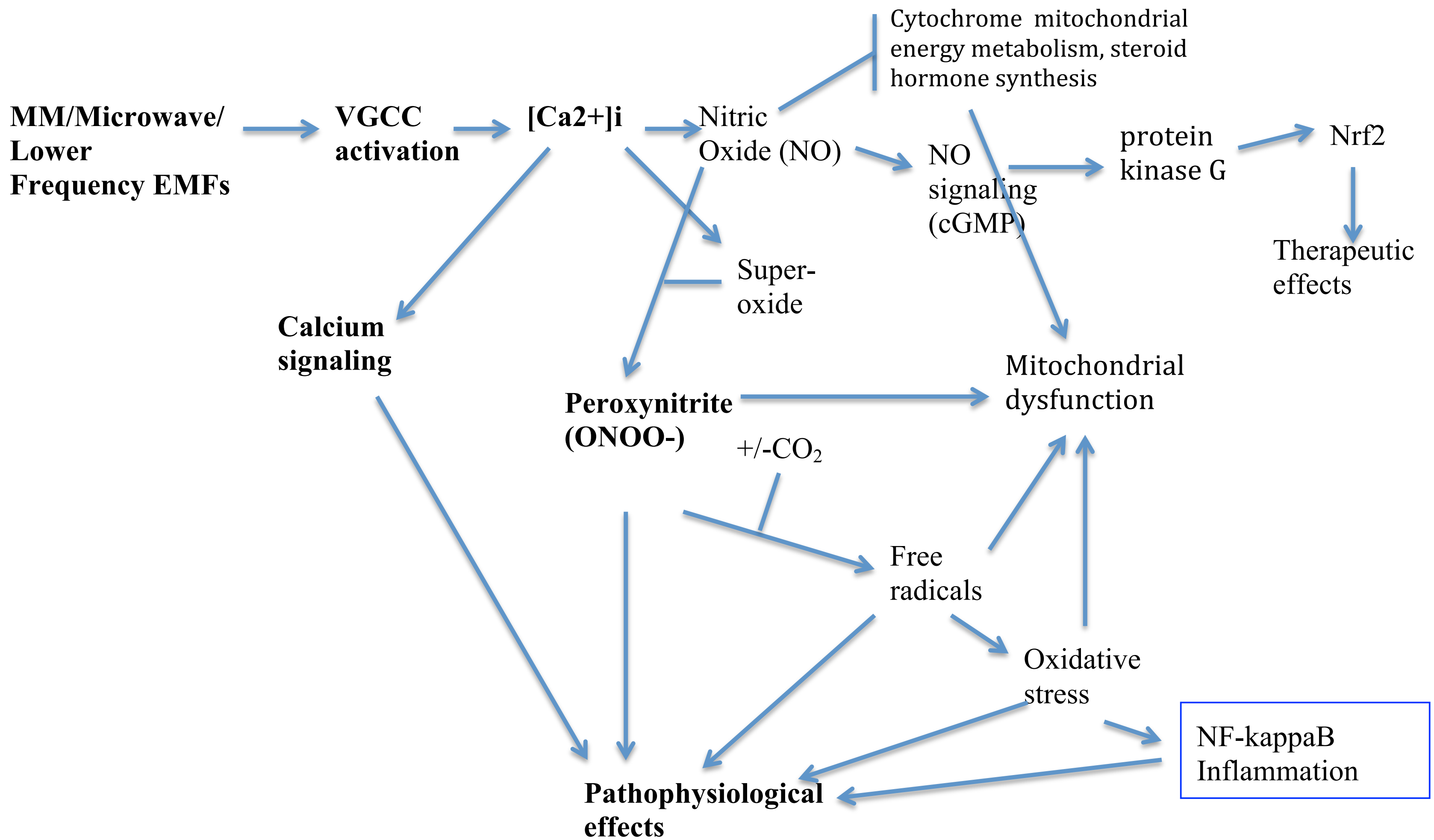
Keller JB, Karal FC, Jr. 1966 Effective Dielectric Constant, Permeability, and Conductivity of a Random Medium and the Velocity and Attenuation Coefficient of Coherent Waves. J Mathemat Phys 7: 661. https://doi.org/10.1063/1.1704979
Kostoff RN, Heroux P, Aschner M, Tsatsakis A. 2020 Adverse health effects of 5G mobile networking technology under real-life conditions. Toxicol Lett 323:35-40. doi: 10.1016/j.toxlet.2020.01.020.
Lebedeva AYu. 2000 The Use of Millimeter Wavelength Electromagnetic Waves in Cardiology. Crit Rev Biomed Eng. 28:339-347 doi: 10.1615/CritRevBiomedEng.v28.i12.460
Lebedeva, NN. 1993 Sensory and subsensory responses of a healthy human being to peripheral influence of low-intensity MM waves. Millimetrovye Volny v Biologii I Meditsina 2:5-23.
Lebedeva, NN. 1994 Human central nervous system response to peripheral action of low-intensity millimeter waves. Radiophysics and Quantum Electronics Journal Volume: 37; Journal Issue: 1 doi 10.1007/BF01039296; Translated from Izvestiya Vysshikh Uchebnykh Zavedenii, Radiofizika; 37: No. 1, 3-29(Jan 1994) doi:10.1007/BF01039296. CIA translated document released 2000/08/10: CIA-
Lebedeva NN. 1998a CNS responses to electromagnetic fields with different biotropic parameters. Biomeditsinskaya Radioelectronika 1:24-36. [in Russian].
Lebedeva NN. 1998b [CNS responses to electromagnetic fields of a health human being to peripheral influence of low-intensity MM waves]. [in Russian] Biomeditsinskaya Radioelectronika 1998 1:24-36. CIA Translated Document Approved for Release 2000/08/10: CIA-RDP96-007923R000100070001-9.
Lebedeva NN, Sulimova OP. 1994 [MM-waves modifying effect on human central nervous system functional state under stress]. Zh Millimetroye Volny v biologii i medicine 1994; 3:16-21 (in Russian)
Li X, Liu C, Liang W, Ye H, Chen W, Lin R, Li Z, Liu X, Wu M. 2013 Millimeter wave promotes the synthesis of extracellular matrix and the proliferation of chondrocyte by regulating the voltage-gated K+ channel. J Bone Miner Metab 2013: 32: 367-377. doi: 10.1007/s00774-013-0513-2
Lu, X.W., Du, L., Kou, L., Song, N., Zhang, Y.J., Wu, M.K., Shen, J.F., 2015. Effects of moderate static magnetic fields on the voltage-gated sodium and calcium channels currents in trigeminal ganglion neurons. Electromagn. Biol. Med. 34, 285–292. http://dx.doi.org/10.3109/15368378.2014.906448.
Lyusov VA, Lebadeva AY, Shchelkunova IG. 1995 MM-wave correction for hemorheologic disorders in patients with unstable stenocardia. Millimetrovye Volny v Biologii i Meditsine 5:23-25. (in Russian)
Maxwell's Equations. Wikipedia. https://en.wikipedia.org/wiki/Maxwell%27s_equations (Accessed March 8, 2020).
Pall ML. 2013 Electromagnetic fields act via activation of voltage-gated calcium channels to produce beneficial or adverse effects. J Cell Mol Med. 2013 Aug; 17(8): 958–965. Published online 2013 Jun 26. doi: 10.1111/jcmm.12088

Pall ML. 2015 Scientific evidence contradicts findings and assumptions of Canadian safety panel 6: Microwaves act through voltage-gated calcium channel activation to induce biological impacts at non-thermal levels, supporting a paradigm shift for microwave/lower frequency electromagnetic field action. Revs Environ Health
Pall ML. 2016a Microwave frequency electromagnetic fields (EMFs) produce widespread neuropsychiatric effects including depression. J Chem Neuroanat 75 (Part B):43-51.
Pall ML. 2016b. Electromagnetic fields act similarly in plants as in animals: Probable activation of calcium channels via their voltage sensor. Curr Chem Biol 10:74-82.
Pall ML. 2018 Wi-Fi is an important threat to human health. Environ Res 164:405-416.
Panagopoulos DJ, Messini N, Karabarbounis A, Philippetis AL, Margaritis LH. 2000 A mechanism for action of oscillating electric fields on cells. Biochem Biophys Res Commun 272:634–40.
Panagopoulos DJ, Johansson O, Carlo GL. 2015 Polarization: A Key Difference between Man-made and Natural Electromagnetic Fields, in regard to Biological Activity. Sci Rep. 2015; 5: 14914. Published online 2015 Oct 12. doi: 10.1038/srep14914
Pikov V, Arakaki X, Harrington M, Fraser SE, Siegel PH. 2010 Modulation of neuronal activity and plasma membrane properties in organotypic cortical slices. J Neural Eng 7 (2010) 045003 doi: 1088/1741-2560/7/4/045003
Pletnev SD. 1991 Application of electromagnetic radiation of millimeter band for treatment of oncological patients [in Russian]. In: Deviatkov ND, Betskii OV, eds. Millimeter Waves in Medicine. Moscow; IRE USSR AcSci, 1991, pp. 76-81.
Pletnev SD, Deviatkov ND, Golant MB, Rebrova B, Balkireva LZ. 1991 EHF radiation in clinical practice [in Rusian]. In International Symposium on Millimeter Waves of Non-thermal Intensity in Medicine. Moscow 1991, pp. 32-42.
Poslavskii MV. 1991 Physical EHF therapy in ulcer treatment and prevention. Technical Digest of the International Symposium on Millimeter Waves of Nonthermal Intensity in Medicine, Moscow, Part 1, pp. 142-146, October 3-6, 1991 (in Russian).
Presto J. 2016 Classical investigations of long-range coherence in biological systems. Chaos 26: 123116; doi.org/10.1063/1.4971963
Sevast'yanova LA. 1983 Biological effects of MM-wave radiation on biological objects. In: ND Devyatkov, ed., Moscow: IRE AN SSSR, pp. 48-62, 1983.
Sevast'yanova LA, Golant MB, Zubenkova ES. 1985 Effect on MM radiowaves on normal tissues and malignant tumors. In: Application of Low-Intensity MM-Wave Radiation in Biology and Medicine, ND Devyatkov, ed., Moscow IRE AN SSSR, pp. 37-49, 1985 (in Russian).
Siegel PH, Pikov V. 2010 Impact of low intensity millimeter waves on cell functions. IET Digital Lib 46(26):70-72.

Sypniewska RK, Millenbaugh NJ, Kiel, JL, Blystone RV, Ringham HN, Mason, PA, Witzmann FA, 2010. Protein changes in macrophages induced by plasma from rats exposed to 35 GHz millimeter waves. Bioelectromagnetics 3, 656-663. doi: 0.1002/bem.20598.
J Tervo, T Setälä, AT Friberg. 2003. Degree of coherence for electromagnetic fields. Optics Express 11::1138.
Titushkin IA, Rao VS, Pickard WF, Moros EG, Shafirstein G, Cho MR. 2009 Altered Calcium Dynamics Mediates P19-Derived Neuron-Like Cell Responses to Millimeter-Wave Radiation. Radiat Res 172 (6): 725-736
Trougakos JP 2019 Nrf2 stress and aging. Aging (Albany, NY) 11:5289-5291.
Wei L, Hu RQ, Qian Y, Wu G. Key elements to enable millimeter wave communications for 5G wireless systems. IEEE Wireless Commun 2014; 21: 136-43.
Wolf E. 2003. Unified theory of coherence and polarization of random electromagnetic beams. Phys Lett 312:263-267.
Wu T, Rapaport TS, Collins CM. 2015 Safe for generations to come. IEEE Microw Mag. 2015 March ; 16(2): 65–84.
Zalyobokskaya NP. 1977 Biological effect of millimeter radiowaves. Vrachebnoye Delo 1977; 3: 116-119. Declassified and Approved for release 2012/05/10: CIA-RDP88B01125R000300120005-6.
https://www.cia.gov/library/readingroom/docs/CIA-RDP88B01125R000300120005-6.pdf (Accessed May 11, 2020)

Fig. 1 legend

Diverse frequency EMFs act via activation of voltage-gated calcium channels (VGCCs) producing increased intracellular calcium $[Ca2+]i$. This leads to production of pathophysiogical 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 Pall, 2018 with permission


MM/Microwave/
Lower
Frequency EMFs
VGCC
activation
[Ca2+]i
Nitric
Oxide (NO)
Cytochrome mitochondrial
energy metabolism, steroid
hormone synthesis
NO
signaling
(cGMP)
protein
kinase G
Nrf2
Therapeutic
effects
Super-
oxide
Calcium
signaling
Peroxynitrite
(ONOO-)
Mitochondrial
dysfunction
+/-CO_2
Free
radicals
Oxidative
stress
NF-kappaB
Inflammation
Pathophysiological
effects