Main Regularities and Health Risks from Exposure to Non-Thermal Microwaves of Mobile Communication

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Abstract — **Various responses to non-thermal microwaves (MW) from mobile communication including adverse health effects related to electrohypersensitivity, cancer risks, neurological effects, and reproductive impacts have been reported while some studies reported no such effects. This presentation provides an overview of the complex dependence of the MW effects on various physical and biological variables, which account for, at least partially, an apparent inconsistence in the published data. Among other variables, dependencies on carrier frequency, polarization, modulation, intermittence, electromagnetic stray fields, genotype, physiological traits, and cell density during exposure were reported. Nowadays, biological and health effects of 5G communication, which will use microwaves of extremely high frequencies (millimeter waves MMW, wavelength 1- 10 mm), are of significant public concern. It follows from available studies that MMW, under specific conditions of exposure at very low intensities below the ICNIRP guidelines, can affect biological systems and human health. Both positive and negative effects were observed in dependence on exposure parameters. In particular, MMW inhibited repair of DNA damage induced by ionizing radiation at specific frequencies and polarizations. To what extend the 5G technology and the Internet of Things will affect the biota and human health is definitely not known. However, based on possible fundamental role of MMW in regulation of homeostasis and almost complete absence of MMW in atmosphere due to effective absorption, which suggests the lack of adaptation to this type of radiation, the health effects of chronic MMW exposures may be more significant than for any other frequency range.**

Keywords — **Thermal and non-thermal effects of microwaves, Millimeter waves, 5G mobile communication, Health risks, Cancer, Physical mechanisms.**

I. Thermal versus Non-Thermal Microwave Effects, Their Main Regularities

Exposures to microwaves (MW, 300 MHz-300 GHz) vary in many parameters: incident power density (PD), specific absorption rate (SAR), frequency/wavelength, polarization (linear, ellipsoidal, circular, unpolarized), continuous wave (CW) and pulsed fields, modulation (amplitude, frequency, phase, complex), far field/near field, static magnetic field (SMF) and stray electromagnetic fields (EMF) of extremely low frequency (ELF, 3-300 Hz) at the location of exposure, overall duration and intermittence of exposure (interrupted, continuous), short-term acute and prolonged chronic exposures. With increased SAR, so-called thermal effects of MW are usually observed that result in significant MW-induced heating. SAR is a main determinate of thermal MW effects. The SAR based safety limits, which intend to protect from the thermal MW effects, were developed based on computer simulation of the MW energy absorption in standardized male phantoms. Thus, they do not take into account individual variability in voxel SAR distribution, which may be observed in dependence on polarization, frequency, age, sex, and pregnancy status [1-8]. In addition, the mobile phone SAR values are usually obtained when the phone is positioned about 2 cm from the standard male phantom head, a condition, which is not usually maintained during mobile phone calls. Other aforementioned physical variables of MW exposure have been linked to occurrence of so-called non-thermal (NT) biological effects, which are induced by MW at intensities well below measurable heating [9-21] [22]. The classification of MW effects into thermal and non-thermal is not based on physics of interaction between MW and biological tissues but rather reflects experimental observation of heating induced by MW exposure, which at SAR levels higher than 2 W/kg may result in thermal injury. Of note, slight temperature increase is also observed in the head tissues during exposure to mobile handset radiation, but this increase is too weak to produce thermal injury [23] and even to be sensed by the exposed subjects [24] while some mobile phone users reported sensation of warmth around the ear [25].

Vilenskaya and co-authors [26] and Devyatkov [27] have reported pioneering data on the NT effects of millimeter waves (MMW, 30-300 GHz, wavelength 1-10 mm in vacuum, to be used in 5G mobile communication) upon exposure of various biological objects. Webb was the first to establish the highly resonant effects of ultra-weak MMW on the induction of λ-phage in lysogenic bacterial E. coli cells [28]. These findings were subsequently corroborated by independent research groups [29, 30]. In these and subsequent studies the observed spectra of MMW action were found to have the following regularities: (1) strong dependence on frequency (frequency windows of resonance type), (2) there was a specific PD threshold below which no effect was observed, and above which the effects of exposure depended only weakly on power over several orders of magnitude (so-called

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sigmoid or S-shaped dependence), (3) the occurrence of MMW effects depended on the duration of exposure, a certain minimum duration of exposure was necessary for an effect to manifest itself. These important regularities of NT MMW effects have previously been confirmed by independent laboratories and reviewed [9, 14-16, 22, 31-34].

Since that time, multiple studies performed by diverse research groups over the World have provided strong evidence for the NT MW effects and have also indicated that there are several consistent regularities in occurrence of these effects: (i) dependence on frequency of "resonance-type" within multiple, while relatively narrow frequency windows; (ii) narrowing of these frequency windows with decreasing intensity of exposure; (iii) dependence on modulation, pulse modulated MW being usually more effective as CW MW; (iv) dependence on polarization, right- or left-circular polarization being more defective then opposite circular and linear polarization specifically for each resonance; (v) power windows and sigmoid dependence on PD within specific intensity windows including super-low PD comparable to intensities from base stations; (vi) thresholds on duration of exposure (coherence time); (vii) dependence on post-exposure time, intermittence and duration of exposure resulting in interplay between accumulated effect and adaptation to exposure; (viii) dependence on cell density suggesting electromagnetic cell-to-cell interaction during exposure; (ix) dependence on several physiological conditions during exposure, such as concentration of divalent ions, oxygen and radical scavengers, stage of cell growth; (x) dependence on genotype. Cell type, sex, age, individual differences, and SMF and stray ELF EMF during exposure can be of importance for the NT MW effects [20, 35]. The data showing dependence of MW effects on extremely low frequency and static magnetic fields at the location of exposure suggested a strategy for reducing health effects from MW of mobile communication.

II. Reproducibility Issues

Eventual non-reproducibility of the NT MW effects in replication studies is a subject of continues debate. As a matter of fact, dependence of the NT MW effects on several biological variables and physical parameters represents an important issue for considering in replication studies. Contrary to some statements, no one from positive studies (reporting NT MW effects) has been dismissed in a valid replication. One of the first studies on MMW effects was published by Webb [36]. The regulation of gene expression for the induction of prophage λ in lysogenic Escherichia coli has been extensively studied at the molecular level. The chain of events leading to induction by DNA-damaging factors, and the involvement of the RecA bacterial protein are well known. Webb has demonstrated, however, that the switching of the prophage genes from lysogenic to lytic development can be accomplished by exposure to MMW at the resonance frequency of 70.4 GHz. We followed the requirements described by Webb [37] as essential for MMW induction of prophage λ and replicated his data [37].

Of note, no one negative study (showing no effects) has been independently replicated. The most representative so far international panel of 30 scientists has stated in the monograph of the International Agency for Research on Cancer (IARC) on carcinogenesis of radiofrequency (RF, 30 kHz - 300 GHz) radiations, pages 101-102: "The reproducibility of reported effects may be influenced by exposure characteristics (including SAR or power density, duration of exposure, carrier frequency, type of modulation, polarization, continuous versus intermittent exposures, pulsed-field variables, and background electromagnetic environment), biological parameters (including cell type, growth phase, cell density, sex, and age) and environmental conditions (including culture medium, aeration, and antioxidant levels)" [35]. The IARC international panel admitted also that some of the inconsistencies between RF studies could be due to differences in species, page 416 [35], and other biological factors, page 104: "Biological systems are complex and factors such as metabolic activity, growth phase, cell density, and antioxidant level might alter the potential effects of RF radiation". Multiple physical variables that may affect study results were considered in the IARC monograph on pages 385-387 [35].

III. Health Risks

Results of several studies of RF effects on sperm quality have recently been reviewed and subjected to meta-analysis using random effect models, in order to determine whether exposure to RF emitted from mobile phones affects human sperm [38]. The sperm quality was measured using parameters, which are most frequently used in clinical settings to assess fertility by motility, viability and concentration. Exposure to mobile phones was associated with reduced sperm motility and viability, while the effects on concentration were more equivocal. These results, being consistent through observational in vivo and experimental in vitro studies, suggested that exposure from mobile phones negatively affects sperm quality.

Most epidemiologic studies indicate detrimental effects of chronic exposure radiation from mobile phones including increased brain cancer risks in heavy mobile phone users, while lower quality studies underestimated this risk [39-42] [43]. The reported brain cancer risk was dependent on type of signal and mutual position of the affected organ and mobile phone.

The majority of studies with chronic exposure to EMF from mobile phones showed detrimental effects including those related to carcinogenicity and also indicated mechanism of these effects, which is based on induction of reactive oxygen species (ROS) [44, 45]. In particular, few recent meta-analyses of available case-control studies have consistently shown that long term mobile phone use (usually ≥ 10 years) is associated with statistically significant increased risks of brain tumors (gliomas and acoustic neuromas) while no such association is seen at shorter usage [39-42]. An increased incidence of glioma in the brain and malignant schwannoma in the heart has recently been found in rats in the National Toxicology Program (NTP) study [46]. Acoustic neuroma, also called vestibular schwannoma, is a similar type of tumor as the malignant schwannoma found in the heart, also benign. Thus, the NTP results, which were obtained upon chronic

MW exposure of laboratory animals, have supported epidemiological human studies, which have found increased risk for glioma and acoustic neuroma.

The NTP findings along with recent replicated animal studies from Germany [47], supplemented other studies and provided sufficient evidence for carcinogenicity of mobile phone exposure in animals. Studies with chronic exposures have also provided evidence for possible mechanisms of MW effects, which involve production of reactive oxygen/nitrogene species. Taking into account the evidence from human epidemiological studies, MW exposure from mobile phones was suggested to be classified as human carcinogen according to the generally accepted Bradford Hill criteria [35, 48]. The interadvisory group of 29 scientists from 18 countries of the International Agency for Research on Cancer (IARC), which is a part of the World Health Organization, has recently stated that the majority of NTP data on carcinogenic bioassay provided evidence for re-evaluating the RF-induced carcinogenesis [49].

Other potential health effects of MW exposure including nervous system diseases and hypersensitivity to electromagnetic fields have recently been reviewed [50, 51].

IV. Mobile Base Stations

Population's exposure to microwaves from base stations continuously grows. Recent studies with individual RF dosimeters indicated that the mobile phone base stations is a major source of whole body exposure to RF [52]. Very few studies are available on effects of MW-exposure from mobile base stations. Notably, most of them indicate adverse health effects, including cancer, fertility and prenatal development under chronic exposures of humans [1-9], mammals [10] and birds [11]. Accumulated dose during chronic exposure seems to be important parameter for assessment of cancer risks from base stations. In Taiwan, Li et al. performed a population-based case-control study and considered cancer incidence cases ≤15 years, which were admitted in 2003-2007 for all neoplasm including leukemia and brain tumors [53]. The cancer risks were estimated versus annual summarized power (ASP, W-year) accumulated during chronic exposures to each of the 71,185 base stations in service in 1998-2007. The annual power density (APD, W-year/km^2) was computed from all base stations. RF exposure of each study case was indicated by the averaged APD within 5 years prior to the neoplasm diagnosis. A was significantly associated with an increased cancer risks for all neoplasm. Thus, this study found a significantly increased risk of all neoplasm in children with higher than median averaged APD (about 168 W-year/km^2) exposure to base stations.

V. Physical Mechanisms

There is an emerging notion that physics of non-equilibrium and nonlinear systems should underlie the physical mechanisms of the NT MW effects [54-63]. According to theoretical analysis of available experimental data on the MW effects at super-weak PD these effects should be considered in frame of quantum-mechanical approach [56, 64]. A fundamental quantum-mechanical mechanism has been suggested by Fröhlich who postulated that biological systems exhibit coherent longitudinal vibrations of electrically polar structures such as biological membranes [57]. According to the Fröhlich's mechanism, when the metabolically driven energy supply exceeds a critical level, the polar structure enters a condition in which a steady state of non-linear oscillation is reached. The Fröhlich's mechanism has also predicted the existence of a resonant interaction of MMW with biosystems [65, 66]. Possible biophysical mechanisms for the NT MW effects have been reviewed elsewhere [67].

VI. 5G versus GSM/UMTS

We tested some signals from GSM (Global System for Mobile Communication, 2G) and UMTS (Universal Mobile Telecommunications System, 3G) mobile phones [68, 69]. Contrary to GSM phones, mobile phones of the 3rd generation irradiate wide-band signal. UMTS MWs may result in higher biological effects due to presence of selective resonance frequency windows.

Most current discussion regarding MW health effects is focused on the 5G mobile communication, which is promptly enrolled in different countries and uses frequency ranges similar to 2G/3G/4G plus MMW. It follows from available studies that MW, under specific conditions of exposure at ultra-weak intensities below the ICNIRP guidelines, can affect biological systems and human health. Both positive and negative effects were observed in dependence on exposure parameters. In particular, MMW inhibited repair of DNA damage induced by ionizing radiation at specific frequencies, modulations and polarizations [21].

While MMW are almost completely absorbed within 1-2 mm in biologically equivalent tissues, it may penetrate much deeper in live human body. Biological objects including human being are not in thermodynamical equilibrium. Thus, except for considering penetration of 5G/MMW into biologically equivalent tissues being in thermodynamical equilibrium, the response of live human body should also be considered. Alive body represents a complicated system with fundamental frequencies; many of them lie in the MMW range. In particular, the acupuncture system (meridians of organs) has been considered as a waveguide system for these MMW fundamental modes in the Soviet/Russian literature. From this point of view, MW penetrates human body far deeply as compared to "dead" model phantoms. Electromagnetic origin of Chinese meridians has been studied in several Soviet research teams. For example, Sit'ko et al. described the frequency of 56.46 GHz, which was found during an ordinary search for therapeutic frequencies based on sensorial reactions of a patient with duodenal ulcer [70]. Negative sensation (defined as spastic contraction of musculus quadricepts femoris) was repeatedly observed under applying MMW at this frequency. This sensory reaction allowed tracking the Chinese stomach meridian by using a static magnet at 4 mT. Exposure at the frequency of 56.46 GHz has worsened health condition of the patient. Thus, this exposure was aborted and the patient received treatment at the resonance therapeutic frequency found by typical positive sensations. After successful healing the duodenal ulcer at the MMW resonance therapeutic frequency, the negative response of the patient to the frequency of 56.46 GHz disappeared.

When a very fast RF pulse enters a human body, it generates a burst of energy (a Brillouin precursor) that can travel much deeper than predicted by the conventional models [71]. Brillouin precursors can be formed by high-speed data signals as used in 5G.

VII. Conclusions

To what extend the 5G technology and the Internet of Things will affect the human health is definitely not known. However, based on possible fundamental role of MMW in regulation of homeostasis [72] and almost complete absence of MMW in atmosphere due to effective absorption, which suggests the lack of adaptation to this type of radiation, the health effects of chronic MMW exposures may be more significant than for any other frequency range. From the health perspectives, implementation of the 5G technology is premature. Extended research with chronic exposure of human cells, animals and man is needed to exclude potentially harmful 5G signals.

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References

[1] O. P. Gandhi, "Yes the children are more exposed to radiofrequency energy from mobile telephones than adults," *IEEE Access,* vol. 3, pp. 985-988, 2015.

[2] R. Asayama, J. Wang, and O. Fujiwara, "Quantitative Relationship between Whole Body Averaged SARs and Voxel SARs in Numerical Human Models of Pregnant Woman and 3-Year-Child for Far-Field Exposure," *Electronics and Communications in Japan,* vol. 97, pp. 28-34, 2014.

[3] E. Cabot, A. Christ, B. Buhlmann, M. Zefferer, N. Chavannes, J. F. Bakker, G. C. van Rhoon, and N. Kuster, "Quantification of RF-exposure of the fetus using anatomical CAD-models in three different gestational stages," *Health Phys,* vol. 107, pp. 369-81, Nov 2014.

[4] T. Nomura, I. Laakso, and A. Hirata, "FDTD computation of temperature elevation in the elderly for far-field RF exposures," *Radiat Prot Dosimetry,* vol. 158, pp. 497-500, Mar 2014.

[5] A. Hirata, Y. Ishii, T. Nomura, and I. Laakso, "Computation of temperature elevation in fetus due to radio-frequency exposure with a new thermal modeling," *Conf Proc IEEE Eng Med Biol Soc,* vol. 2013, pp. 3753-6, 2013.

[6] L. Ae-Kyoung and K. Jong-Hwa, "Children's Mobile Phone Use and Dosimetry," *Journal of Electromagnetic Engineering and Science,* vol. 15, pp. 167-172, 2015.

[7] C. Li, Z. Chen, L. Yang, B. Lv, J. Liu, N. Varsier, A. Hadjem, J. Wiart, Y. Xie, L. Ma, and T. Wu, "Generation of infant anatomical models for evaluating electromagnetic field exposures," *Bioelectromagnetics,* vol. 36, pp. 10-26, Jan 2015.

[8] N. Varsier, S. Dahdouh, A. Serrurier, J. P. De la Plata, J. Anquez, E. D. Angelini, I. Bloch, and J. Wiart, "Influence of pregnancy stage and fetus position on the whole-body and local exposure of the fetus to RF-EMF," *Physics in Medicine and Biology,* vol. 59, pp. 4913-4926, Sep 7 2014.

[9] A. G. Pakhomov, Y. Akyel, O. N. Pakhomova, B. E. Stuck, and M. R. Murphy, "Current state and implications of research on biological effects of millimeter waves: a review of the literature," *Bioelectromagnetics,* vol. 19, pp. 393-413, 1998.

[10] H. Lai, "Biological effects of radiofrequency electromagnetic field," in *Encyclopedia of Biomaterials and Biomedical Engineering*, G. E. Wnek and G. L. Bowlin, Eds., ed New York, NY: Marcel Decker, 2005, pp. 1-8.

[11] O. V. Betskii, N. D. Devyatkov, and V. V. Kislov, "Low intensity millimeter waves in medicine and biology," *Crit Rev Biomed Eng,* vol. 28, pp. 247-268, 2000.

[12] W. R. Adey, "Cell and molecular biology associated with radiation fields of mobile telephones," in *Review of Radio Science, 1996-1999*, W. R. Stone and S. Ueno, Eds., ed Oxford: Oxford University Press, 1999, pp. 845-872.

[13] S. Banik, S. Bandyopadhyay, and S. Ganguly, "Bioeffects of microwave - a brief review," *Bioresour Technol,* vol. 87, pp. 155-159, Apr 2003.

[14] N. D. Devyatkov, M. B. Golant, and O. V. Betskij, *Peculiarities of usage of millimeter waves in biology and medicine (in Russian)*. Moscow: IRE RAN, 1994.

[15] W. Grundler, V. Jentzsch, F. Keilmann, and V. Putterlik, "Resonant cellular effects of low intensity microwaves," in *Biological Coherence and Response to External Stimuli*, H. Frųlich, Ed., ed Berlin: Springer-Verlag, 1988, pp. 65-85.

[16] V. D. Iskin, *Biological effects of millimeter waves and correlation method of their detection (in Russian)*. Kharkov: Osnova, 1990.

[17] Y. G. Grigoriev, "Bioeffects of modulated electromagnetic fields in the acute experiments (results of Russian researches)," in *Annual of Russian National Committee on Non-Ionisng Radiation Protection*, ed Moscow: ALLANA, 2004, pp. 16-73.

[18] Y. G. Grigoriev, V. S. Stepanov, V. N. Nikitina, N. B. Rubtcova, A. V. Shafirkin, and A. L. Vasin, "ISTC Report. Biological effects of radiofrequency electromagnetic fields and the radiation guidelines. Results of experiments performed in Russia/Soviet Union," Institute of Biophysics, Ministry of Health, Russian Federation, Moscow2003.

[19] M. Cifra, J. Z. Fields, and A. Farhadi, "Electromagnetic cellular interactions," *Progress in Biophysics and Molecular Biology,* vol. 105, pp. 223-246, 2011.

[20] I. Y. Belyaev, "Dependence of non-thermal biological effects of microwaves on physical and biological variables: implications for reproducibility and safety standards," *European Journal of Oncology - Library,* vol. 5, pp. 187-218, 2010.

[21] I. Y. Belyaev, V. S. Shcheglov, E. D. Alipov, and V. D. Ushalov, "Nonthermal effects of extremely high-frequency microwaves on chromatin conformation in cells in vitro - Dependence on physical, physiological, and genetic factors," *IEEE Transactions on Microwave Theory and Techniques,* vol. 48, pp. 2172-2179, Nov 2000.

[22] A. G. Pakhomov and M. R. Murphy, "Low-intensity millimeter waves as a novel therapeutic modality," *Ieee Transactions on Plasma Science,* vol. 28, pp. 34-40, Feb 2000.

[23] A. A. Marino, P. Y. Kim, and C. Frilot Ii, "Trigeminal neurons detect cellphone radiation: Thermal or nonthermal is not the question," *Electromagn Biol Med,* vol. 36, pp. 123-131, 2017/04/03 2017.

[24] H. Dorn, G. Schmid, T. Eggert, C. Sauter, T. Bolz, and H. Danker-Hopfe, "Experimental investigation of possible warmth perception from a head exposure system for human provocation studies with TETRA handset-like signals," *Bioelectromagnetics,* vol. 35, pp. 452-8, Sep 2014.

[25] A. Bortkiewicz, E. Gadzicka, W. Szymczak, and M. Zmyslony, "Changes in tympanic temperature during the exposure to electromagnetic fields emitted by mobile phone," *International Journal of Occupational Medicine and Environmental Health,* vol. 25, pp. 145-150, 2012.

[26] R. L. Vilenskaya, A. Z. Smolyanskaya, V. G. Adamenko, Z. N. Buldasheva, E. A. Gelvitch, M. B. Golant , and D. Y. Goldgaber, "Induction of the lethal colicin synthesis in E. coli K12 C600 (E1) by means the millimeter radiation (in Russian)," *Bull. Eksperim. Biol. Med.,* vol. 4, pp. 52-54, 1972.

[27] N. D. Devyatkov, "Influence of electromagnetic radiation of millimeter range on biological objects (in Russian)," *Usp Fiz Nauk,* vol. 116, pp. 453-454, 1973.

[28] S. J. Webb, "Factors affecting the induction of Lambda prophages by millimetre waves," *Phys Letts,* vol. 73A, pp. 145-148, 1979.

[29] K. V. Lukashevsky and I. Y. Belyaev, "Switching of prophage lambda genes in Escherichia coli by millimeter waves," *Medical Science Research,* vol. I8, pp. 955-957, 1990.

[30] V. S. Bannikov and S. B. Rozhkov, "[Resonance absorption of millimeter waves by E. coli K-12(lambda) bacterial cells]," *Dokl Akad Nauk SSSR,* vol. 255, pp. 746-8, 1980.

[31] M. B. Golant, "Resonance effect of coherent millimeter-band electromagnetic waves on living organisms (in Russian)," *Biofizika,* vol. 34, pp. 1004-1014, Nov-Dec 1989.

[32] E. Postow and M. L. Swicord, "Modulated fields and "window" effects," in *CRC Handbook of Biological Effects of Electromagnetic Fields*, C. Polk and E. Postow, Eds., ed Boca Raton, FL: CRC Press, 1986, pp. 425-460.

[33] I. Y. Belyaev, "Some biophysical aspects of the genetic effects of low intensity millimeter waves," *Bioelectrochem Bioenerg,* vol. 27, pp. 11-18, 1992.

[34] G. J. Hyland, "Physics and biology of mobile telephony," *Lancet,* vol. 356, pp. 1833-6, Nov 25 2000.

[35] IARC, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. Non-ionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields* vol. 102. Lyon, France: IARC Press, http://monographs.iarc.fr/ENG/Monographs/vol102/mono102.pdf, 2013.

[36] S. J. Webb, "Factors Affecting the Induction of Lambda Prophages by Millimeter Microwaves," *Physics Letters A,* vol. 73, pp. 145-148, 1979.

[37] K. V. Lukashevsky and I. Y. Belyaev, "Switching of prophage lambda genes in Escherichia coli by millimetre waves," *Medical Science Research,* vol. 18, pp. 955-957, 1990.

[38] J. A. Adams, T. S. Galloway, D. Mondal, S. C. Esteves, and F. Mathews, "Effect of mobile telephones on sperm quality: a systematic review and meta-analysis," *Environ Int,* vol. 70, pp. 106-12, Sep 2014.

[39] M. Yang, W. Guo, C. Yang, J. Tang, Q. Huang, S. Feng, A. Jiang, X. Xu, and G. Jiang, "Mobile phone use and glioma risk: A systematic review and meta-analysis," *PLoS One,* vol. 12, p. e0175136, 2017.

[40] A. Bortkiewicz, E. Gadzicka, and W. Szymczak, "Mobile phone use and risk for intracranial tumors and salivary gland tumors - A meta-analysis," *Int J Occup Med Environ Health,* vol. 30, pp. 27-43, Feb 21 2017.

[41] M. Prasad, P. Kathuria, P. Nair, A. Kumar, and K. Prasad, "Mobile phone use and risk of brain tumours: a systematic review of association between study quality, source of funding, and research outcomes," *Neurological Sciences,* vol. 38, pp. 797-810, May 2017.

[42] Y. Wang and X. Guo, "Meta-analysis of association between mobile phone use and glioma risk," *J Cancer Res Ther,* vol. 12, pp. C298-C300, 2016.

[43] A. G. Levis, N. Minicuci, P. Ricci, V. Gennaro, and S. Garbisa, "Mobile phones and head tumours. The discrepancies in cause-effect relationships in the epidemiological studies - how do they arise?," *Environ Health,* vol. 10, p. 59, 2011.

[44] I. Belyaev, "Health effects of chronic exposure to radiation from mobile communication," in *Mobile Communications and Public Health*, M. Markov, Ed., ed Boca Raton: CRC Press, 2019, pp. 65-99.

[45] I. Belyaev, "Duration of Exposure and Dose in Assessing Nonthermal Biological Effects of Microwaves," in *Dosimetry in Bioelectromagnetics*, M. Markov, Ed., ed Boca Raton, London. New York: CRC Press, 2017, pp. 171-184.

[46] NTP. (2018, National Toxicology Program, Peer Review of the Draft NTP Technical Reports on Cell Phone Radiofrequency Radiation, https://ntp.niehs.nih.gov/ntp/about_ntp/trpanel/2018/march/peerreview20180328_508.pdf. *National Institute of Environmental Health Sciences Research Triangle Park,* 1-48. Available: https://ntp.niehs.nih.gov/ntp/about_ntp/trpanel/2018/march/peerreview20180328_508.pdf

[47] A. Lerchl, M. Klose, K. Grote, A. F. Wilhelm, O. Spathmann, T. Fiedler, J. Streckert, V. Hansen, and M.

Clemens, "Tumor promotion by exposure to radiofrequency electromagnetic fields below exposure limits for humans," *Biochem Biophys Res Commun,* vol. 459, pp. 585-90, Apr 17 2015.

[48] M. Carlberg and L. Hardell, "Evaluation of Mobile Phone and Cordless Phone Use and Glioma Risk Using the Bradford Hill Viewpoints from 1965 on Association or Causation," *Biomed Res Int,* vol. 2017, p. 9218486, 2017.

[49] M. M. Marques, A. Berrington de Gonzalez, F. A. Beland, P. Browne, P. A. Demers, D. W. Lachenmeier, T. Bahadori, D. K. Barupal, F. Belpoggi, P. Comba, M. Dai, R. D. Daniels, C. Ferreccio, O. A. Grigoriev, Y.-C. Hong, R. N. Hoover, J. Kanno, M. Kogevinas, G. Lasfargues, R. Malekzadeh, S. Masten, R. Newton, T. Norat, J. J. Pappas, C. Queiroz Moreira, T. Rodríguez, J. Rodríguez-Guzmán, V. Sewram, L. Zeise, L. Benbrahim-Tallaa, V. Bouvard, I. A. Cree, F. El Ghissassi, J. Girschik, Y. Grosse, A. L. Hall, M. C. Turner, K. Straif, M. Korenjak, V. McCormack, K. Müller, J. Schüz, J. Zavadil, M. K. Schubauer-Berigan, and K. Z. Guyton, "Advisory Group recommendations on priorities for the IARC Monographs," *Lancet Oncol,* 2019.

[50] D. Belpomme, L. Hardell, I. Belyaev, E. Burgio, and D. O. Carpenter, "Thermal and non-thermal health effects of low intensity non-ionizing radiation: An international perspective," *Environ Pollut,* vol. 242, pp. 643-658, Nov 2018.

[51] I. Belyaev, A. Dean, H. Eger, G. Hubmann, R. Jandrisovits, M. Kern, M. Kundi, H. Moshammer, P. Lercher, K. Muller, G. Oberfeld, P. Ohnsorge, P. Pelzmann, C. Scheingraber, and R. Thill, "EUROPAEM EMF Guideline 2016 for the prevention, diagnosis and treatment of EMF-related health problems and illnesses," *Rev Environ Health,* vol. 31, pp. 363-97, Sep 01 2016.

[52] J. Choi, J. H. Hwang, H. Lim, H. Joo, H. S. Yang, Y. H. Lee, M. Eeftens, B. Struchen, M. Roosli, A. K. Lee, H. D. Choi, J. H. Kwon, and M. Ha, "Assessment of radiofrequency electromagnetic field exposure from personal measurements considering the body shadowing effect in Korean children and parents," *Science of the Total Environment,* vol. 627, pp. 1544-1551, Jun 15 2018.

[53] C. Y. Li, C. C. Liu, Y. H. Chang, L. P. Chou, and M. C. Ko, "A population-based case-control study of radiofrequency exposure in relation to childhood neoplasm," *Sci Total Environ,* vol. 435-436, pp. 472-8, Oct 1 2012.

[54] F. Kaiser, "Coherent oscillations - their role in the interaction of weak EMF-fields with cellular systems," *Neural Network World,* vol. 5, pp. 751-762, 1995.

[55] A. Scott, *Nonlinear Science: Emergence and Dynamics of Coherent Structures*. Oxford: Oxford University Press, 1999.

[56] V. N. Binhi, *Magnetobiology: Underlying Physical Problems*. San Diego: Academic Press, 2002.

[57] H. Frohlich, "Long-range coherence and energy storage in biological systems," *Int J Quantum Chem,* vol. 2, pp. 641-652, 1968.

[58] M. Bischof, "Introduction to integrative biophuysics," in *Integrative biophysics*, F.-A. Popp and L. V. Beloussov, Eds., ed Dordrecht: Kluwer Academic Publishers, 2003, pp. 1-115.

[59] A. H. Frey, "Differential biologic effects of pulsed and continuous electromagnetic fields and mechanisms of effect," *Ann N Y Acad Sci,* vol. 238, pp. 273-9, 1974.

[60] W. Grundler, F. Kaiser, F. Keilmann, and J. Walleczek, "Mechanisms of electromagnetic interaction with cellular systems," *Naturwissenschaften,* vol. 79, pp. 551-9, Dec 1992.

[61] V. N. Binhi and A. B. Rubin, "Magnetobiology: the kT paradox and possible solutions," *Electromagn Biol Med,* vol. 26, pp. 45-62, 2007.

[62] L. Brizhik, A. Eremko, B. Piette, and W. Zakrzewski, "Effects of periodic electromagnetic field on charge transport in macromolecules," *Electromagn Biol Med,* vol. 28, pp. 15-27, 2009.

[63] F. Srobar, "Role of Non-Linear Interactions by the Energy Condensation in Frohlich Systems," *Neural Network World,* vol. 19, pp. 361-368, 2009.

[64] I. Y. Belyaev, Y. D. Alipov, V. S. Shcheglov, V. A. Polunin, and O. A. Aizenberg, "Cooperative response of Escherichia-Coli-cells to the resonance effect of millimeter waves at super low-intensity," *Electro- and Magnetobiology,* vol. 13, pp. 53-66, 1994.

[65] H. Frohlich, "Long range coherence and the action of enzymes," *Nature,* vol. 228, p. 1093, Dec 12 1970.

[66] H. Frohlich, "The extraordinary dielectric properties of biological materials and the action of enzymes," *Proc Natl Acad Sci U S A,* vol. 72, pp. 4211-5, Nov 1975.

[67] I. Belyaev, "Biophysical Mechanisms for Nonthermal Microwave Effects," in *Electromagnetic Fields in Biology and Medicine*, M. Markov, Ed., ed Boca Raton, London, New York: CRC Press, 2015, pp. 49-68.

[68] E. Markova, L. O. Malmgren, and I. Y. Belyaev, "Microwaves from Mobile Phones Inhibit 53BP1 Focus Formation in Human Stem Cells More Strongly Than in Differentiated Cells: Possible Mechanistic Link to Cancer Risk," *Environmental and Health Perspective,* vol. 118, pp. 394-9, Mar 2010.

[69] I. Y. Belyaev, E. Markova, L. Hillert, L. O. Malmgren, and B. R. Persson, "Microwaves from UMTS/GSM mobile phones induce long-lasting inhibition of 53BP1/gamma-H2AX DNA repair foci in human lymphocytes," *Bioelectromagnetics,* vol. 30, pp. 129-41, Feb 2009.

[70] S. P. Sitko, E. A. Andreev, and I. S. Dobronravova, "The whole as a result of self-organization," *J Biol Phys,* vol. 16, pp. 71-73, December 01 1988.

[71] K. E. Oughstun, "Optimal Penetration in Debye-Model Dielectrics Using the Brillouin Precursor Pulse," *Ieee Transactions on Antennas and Propagation,* vol. 65, pp. 1832-1835, Apr 2017.

[72] H. Frohlich, "The Biological Effects of Microwaves and Related Questions," in *Advances in Electronics and Electron Physics*. vol. 53, L. Marton and C. Marton, Eds., ed New York: Academic Press, 1980, pp. 85-152.