Review

Nonionizing Electromagnetic Irradiations; Biological Interactions, Human Safety

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ABSTRACT

Human is usually exposed to environmental radiation from natural and man-made sources. Therefore, it is important to investigate the effects of exposure to environmental radiation, partly related to understanding and protecting against the risk of exposure to environmental radiation with beneficial and adverse impacts on human life. The rapid development of technologies causes a dramatic enhancement of radiation in the human environment. In this study, we address the biological effects caused by different fractions of non-ionizing electromagnetic irradiation to humans and describe possible approaches for minimizing adverse health effects initiated by radiation. The main focus was on biological mechanisms initiated by irradiation and represented protection, and safety approaches to prevent health disorders.

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Keywords

Human Safety; Health Disorders; Radiation; Protection; Radiation, Nonionizing; Background Radiation

Introduction

Studying human health in a living environment is always a fascinating topic for scientists [1], partly related to understanding and protecting against the risk of exposure to environmental radiation from natural and man-made. Also, human life is impacted negatively and positively by these environmental radiations [2]. Solar radiation is the main natural radiation composed of ionizing and non-ionizing electromagnetic irradiations that the non-ionizing electromagnetic radiations are categorized into four fractions based on wavelengths: ultraviolet (UV), visible light, infrared (IR), and radiofrequency (RF) radiations [3].

The quick advance of technology has resulted in a significant increase in radiation in the human environment. Extended uses of the tanning bed, welding torches, smart cellphones, wireless, laptop, and artificial lighting during the night lead to widely radiation background in the human environment which is a serious threat to human health particularly children and elders. Thus, it is essential to reveal long-term hazards to develop adequate awareness and protective approaches for safe utilization and exposure. This review addresses the biological effects caused by different fractions of non-ionizing electromagnetic irradiation to humans and describes possible approaches for minimizing adverse health

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effects initiated by radiation.

UV light

A part of non-ionizing electromagnetic radiation is UV light comprised of a distinct spectral area of 200-400 nm. The sun is the main source of UV radiation, although human handling sources such as tanning beds and welding torches can irradiate UV lights that dramatically influence human health [4]. Generally, UV-spectrum exposure can be further classified into UV-C (200-280 nm), UV-B (280-320 nm), and UV-A (320-400 nm) by wavelength. UV-C is not as troubling as the photons absorbed by the ozone layer and thus do not affect the surface of the earth. Photoprotection from both UV-A and UV-B radiation is a problem for healthcare professionals [5] that UV-B rays can penetrate deeply to the dermis layer of skin and induce molecular changes such as vitamin D_3 synthesis from cholesterol metabolites [6]. In addition, UV lights can alleviate the pain and cause well feeling with increased beta-endorphin synthesis by keratinocytes [7].

In the last decade, UV disinfection has advanced into a practical process. Protozoa, bacteria, and viruses are inactivated by UV disinfection devices [8]. UV radiation also breaks down the microorganisms' genetic structure and restricts their reproductive capacity and eventually causes death [9] and UV germicidal is a result of sunlight. Some germicidal radiation (UV-C) on earth dose not penetrate and state-of-the-art technology could be used appropriately to transform electrical power into UV germicidal radiation. UV-C easily destroys live bacteria, viruses, and cysts from airborne organisms, soil, and water. Likewise, low doses of radiation exposure might not have negative effects on the cells. When the exposure time is lengthened or the UV light intensity is amplified, the number of unrepaired dimers and mutations likely increase [10].

UV light and biological systems

Vitamin D_3 is mainly synthesized from cholesterol metabolites by UV-B interaction, inducing conversion of 7- dehydrocholesterol to an inactive form of vitamin D_3 that following two hydroxylation events can actively regulate various cellular mechanisms [11]. Based on the preclinical studies, UV-A and UV-B radiation promote beta-endorphin expression in keratinocytes. It was also observed that keratinocytes which irradiated to both UV-A and UV-B could produce a higher amount of beta-endorphin than those exposed to UV-A alone. Beta-endorphins are opioid peptides, result in relieving pain and feeling healthier and happiness [12]. Further, UV-B radiation helps improve cardiac function and decrease blood pressure by increasing blood vitamin D_3 values [12]. However, UV rays are essential for regulating some physiologic processes, prolonged and severe irradiation interact with cellular macromolecules and increas likely DNA damage and health disorders [13]. UV-B energy is more than UV-A and efficiently absorbed by upper skin layers whereas, UV-A mostly penetrates the dermis layer [14].

UV-B initiates DNA damage directly and indirectly through the generation of reactive species. DNA molecules weakly absorb UV-A rays and indirectly form chromosomal mutations [13]. Even though, cellular DNA can absorb UV-A rays only 4.2 fold lower compared to UV-B, UV-A rays can also directly affect DNA molecules and the photoproducts of UV-A are more cytotoxic than UV-B [15]. After sunlight or UV exposure, these photons penetrate the skin and cellular DNA can absorb them, leading to structural changes in DNA (DNA dimerization, distortion, and breaks in DNA structure, a transition of pyrimidines) [16]. The cell cycle can progress ineffectively due to monitoring weakly by checkpoint mechanisms [17]. Subsequently, repair DNA pathways may not only attenuate deleterious effects of these photoproducts but also replicate and accumulate mutated genome, resulting in age-related diseases tumorigenic transformation of human skin cells [18].

The UV protectors

Radiation protection against adverse effects of UV radiation is inevitable that is attracted considerable personal care equipment such as clothes, sunglasses, and sunscreens. However, the UV filters are applied in standard cloth, cap or hat, and gloves [19], sunscreens are the main approaches against adverse effects of UV radiation [20]. UV filters are molecular complexes that can absorb, reflect, or scatter UV rays. Two types of UV protectors contain inorganic filters and synthetic organic that its protectors are aromatic compounds with photo-stability nature absorbing UV rays and altering them into weaker energy. While inorganic filters are different metal oxides applied as a particle film to provide UV protection, they scatter and reflect UV rays, without any decomposing by irradiation [21] with functionality, widely depending on their size. Reducing particle size is possible to develop a new sunscreen with clear skin [22]. Furthermore, inorganic filters are the first choice as a UV blocker for a patient with skin allergy due to stability and non-cytotoxic features [23].

The food and drug administration is the organization approving UV filters consumption with parameters expressing the protection efficiency of clothes, sunglasses, and sunscreens. The sun protection ability of these cosmetic products was determined by in vivo and in vitro studies [20]. The efficiency of a sunscreen against UV-B radiation can be determined by the sun protection factor, equal to the UV protection factor that determines the level of clothing offered protection [24], i.e. several systems describe a sunscreen that provides UV-A protection. Persistent pigment darkening is a popular in vivo technique for determining the UV-A protection factor. In addition, a star rating system used in the UK indicates the degree of UV-A protection offered by sunscreen and one-star represents the lowest UV-A protection, whereas five stars is an indicator of the highest UV-A protection [20].

Zinc oxide (ZnO) is an inorganic broad-spectral UV blocker, approximately found in 50% of cosmetic care products with a 200-400 nm particle size. As the nano-particle has a broader surface area to volume proportion, it provides efficiently higher UV protection than micron-sized one. The particle size determines the various physiological and biological specialties. The appropriate physiochemical features of ZnO cause to select as a good UV filter in clothing and sunglasses. Despite nanoparticles, ZnO is well-known as the best UV protector, while the safety of ZnO is not entirely known. Several studies on animal models indicated that the safety of nano-sized ZnO is dependent on dose, duration, and administration method [25].

Titanium dioxide (TiO_2) is one of the most common inorganic UV absorbents, exerting broad-spectrum UV protection. The physicochemical properties of TiO_2 include whitening feature due to the high optical refractive index, presenting naturally into three crystalline structures with a more remarkable ability for UV-B filtration than ZnO, transparent property in nano-sized TiO_2 (10-20 nm), and higher UV absorbance in nano-sized TiO_2 [26]. Also, recent data indicated TiO_2 that might promote the incidence of lung carcinogenesis. Thus, TiO_2 is categorized as a 2B carcinogen agent by the International Agency for Research on Cancer [27].

Visible Light and IR

A portion of electromagnetic radiations is visible for human eyes included spectral areas 400-780 nm wavelengths [28]. IR radiation is included electromagnetic fields with spectral regions 760 nm -1mm wavelength, influencing biological systems. The health effects of visible and IR lights are also dependent on the intensity, duration, timing, and spectral content of light [29]. The higher wavelength spectrum of IR is called an IR-A (wavelength 760-1400 nm) that can intensify the adverse effect of UV-A [30].

Biological Interactions of Visible Light and IR

The most important biological impact of visible light imagins forming vision. Human eyes have three types of photoreceptors absorbing visible light and sending information to the nervous system that the two types of photoreceptors contribute to the reconstruction of the image and one participates in absorbing a blue fraction of visible light [31], included in a spectral area with a wavelength of 400-495 nm. This fraction of visible light controls non-image-forming responses such as circadian rhythm, suppressing melatonin generation in the nervous system [32]. Misalignment of circadian rhythmicity is a problem of seasonal changes and modern society [33, 34]. The over-generation of melatonin causes some people to become depressed and sleepy in the winter season with the decreased sunlight intensity. Melatonin has also been used as phototherapy for depression and behavioral diseases [35]. In contrast, blue light-emitted diodes are widely used in industrial environments, laptops, and smartphones [34]. Blue light has the lowest photon wavelengths in the visible spectrum and can penetrate deeply to dermis layers and eyes lens, potentially damaging to skin and eyes tissues. The retina tissue contains many polyunsaturated fatty acids and high oxygen tension. Therefore, it is highly susceptible to photooxidative damage [36], and nearly 50% of photooxidative damage is formed in the skin by radiation, originating from high doses of visible and IR photons [37]. These photons can degrade skin antioxidants such as carotenoids and indirectly promote radical production [30]. Moreover, the visible light could directly induce O_2 and NO generations and result in depleting tissues, antioxidants enzymes, promoting inflammatory and angiogenic cytokines, and apoptotic proteins, and leading to visible light-related aging [38]. The visible light was well-known, degrades cutaneous carotenoids, and indirectly induces oxidative damage to cutaneous cells [30]. Excessive exposure to artificial blue lights also involves several health disorders such as obesity and cancer [39]. Excessive use of artificial lights at night promotes the possibility of metabolic disorders. Recent data have been indicated shiftwork is a potential risk for carcinogenesis, obesity, and cardiovascular disorders, related to disrupting melatonin synthesis [40].

Visible light exposure protection

Largely using artificial blue light at nighttime promotes sleep disruption and age-related diseases such as macular degeneration. The photooxidative mechanisms play the most role in the pathogenesis of these diseases [41]. Also, the increased antioxidant capacity is an excellent protective approach to prevent health disorders. In this case, Koushan et al. evaluated the dietary supplementation effects on health disorders of irradiation [42]. Personal care products have also been formulated with various natural antioxidants to minimize photooxidative damage to skin cells [43]. Wang et al. showed that Dietary proanthocyanidins (PAC) extracted from berries and sea buckthorn seed attenuated oxidative and inflammatory alterations induced by visible light exposure in vivo [44]. PACs are some of the natural phenolic components efficiently protecting visible lights induced retinal degeneration [45]. These active components are metabolized in gastrointestinal systems and converted to small-distributed metabolites to the retina by blood circulation [44]. Although metal oxide-UV filters scatter and reflect the visible spectral region, PACs do not block visible lights [23]. Some commercial cosmetic producers asserted new colored sunscreens with visible light-blocking, including nanoparticles coated with a fine film of melanin [46].

Furthermore, recent data indicated that blue light shield eyewear, especially at night, can be a safe and straightforward approach to control circadian rhythm misalignment. In Japan, using blue-light shield eyewear is widespread, and epidemiologic studies showed that blue-light shield eyewear use before bedtime could increase sleep quality in healthy adults [34].

Radiofrequency fields (RFF)

RF light is a broad wavelength spectral area of non-ionizing electromagnetic radiation 1mm-100 km, categorized based on wavelength into two microwaves (1-1000 mm) and radio wave frequencies (1m-100 km) classes. RFFs have two main physical characteristics, including frequency ranges (Hz), radiation intensity (W/m^2), and specific absorption rate (SAR, W/kg) [47]. Although RFF energy is directly related to frequency levels, the intensity of radiation inversely influences RFF energy [48]. The microwaves contain the highest frequency and lowest intensity of RFFs (85). Large applications are developed with different radio waves boundaries such as cellphone, telephones, airport scanners, radars, television, wireless, laptop, tablet, and microwave ovens [49]. The excessive use of cell phones, with various RF ranges, and wireless technologies, increase public concerns [50].

Biological Impacts of RFF

Some studies have investigated the health effects of RFFs [51-53], dependent on wavelength and frequency ranges [48]. A higher RFF can penetrate lower to human tissues interact poorly with polar molecules, and its exposure exerts thermal impacts on biological systems [54]. Due to their low energy, RFF cannot only activate orbital electrons of the molecules, but it increases tissue temperature by incremental molecular vibrational/rotational state, disturbing the cellular electrochemical balance subsequently [55]. Thermal and non-thermal effects of RFFs are dependent on the physical features of applied RFF. If SAR of RFF is above 1 W/kg, thermal effects are induced, whereas, SRA below 0.1 W/Kg needs to exert non-thermal [56]. Additionally, some RFFs have non-thermal effects on cells, such as changing electrochemical in DNA [57], promoting the electron transfer chain in mitochondria [58], increasing free iron in the blood by restricting iron chelation with ferritin protein [59], promoting the generation of radicals especially hydroxyl radicals by Fenton reaction and mechanochemical transformation of water molecules [49], altering in protein conformations through oxidative damage [60], and disturbing the intracellular Ca hemostasis [61]. As a result, RFFs potentially initiate cellular dysregulation, proliferation, and dysfunction [49]. Although there are many results regarding RFFs impacts on embryo development, reproduction, and nervous systems, it has also been shown that RFFs can trigger developmental and differential capacity of the embryo and stem cells significantly [62].

RFF Considerations

It has been discovered that RFF can cause alterations in nerve cells in the central nervous system. A recent study showed that the frequency ranges between 30 kHz to 300 GHz of RFFs may be carcinogenic agents for humans [63] that is an awareness of smart cellphones users. Standard limitations were designed at different governments such as the U.S, and Europe. The limitations were designed principally based on an animal model exposed to short-term high-power RFFs to prevent thermal effects. In order to set protection standards, some parameters such as exposure duration, the intensity of RFFs, an individual's tolerance for RFF exposure should be considered [64]. According to the ICNIRP standard limitations, the RFFs with power densities between 10 W/cm^2 (general public) and 50 W/cm^2 (for the occupational group) with frequency ranges 10- 300 GHz are safe. In other words, the federal communications commission limitations accept the maximum frequency ranges of RFFs exposure between 0.3 MHz to 100 GHz. Based on the guidelines, SAR levels of 4 W/kg for the whole body are identified as a working threshold for adverse thermal effects induced by RFFs [55].

Discussion

An extensive review of the scientific literature shows that non-ionizing electromagnetic fractions can interact dramatically with biological systems [65]. Despite excessive sunlight sunlight inducing inducing various health disorders, less solar exposure certainly promotes susceptibility to chronic diseases such as depression, infectious diseases, and vitamin D deficiency. Also, in today's world, human lives in an environment with extended RF and artificial background and technologies are becoming an imperative part of life [66]. Thus, the government and the world health organization (WHO) have arranged standard guidelines to provide safe modern life.

Conclusion

In conclusion, advancing radiobiology science and identifying the harmful effects of non-ionizing radiation, the health protection and awareness providing using safely are needed more than ever.

Authors' Contribution

All authors uniformly, were involved in the design of the study, also, were involved in the preparing and revising the manuscript. All the authors read, modified, and approved the final version of the manuscript.

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Conflict of Interest

None

References

1. Akbari H, Satkin M, Ganji M, Akbari H, Gholami FM. Standardization and study of psychological properties of the HSE Stress Questionnaire. *Iran Red Crescent Med J*. 2017;**19**(3):e40466. doi: 10.5812/ircmj.40466.
2. Cornacchia S, La Tegola L, Maldera A, Pierpaoli E, et al. Radiation protection in non-ionizing and ionizing body composition assessment procedures. *Quant Imaging Med Surg*. 2020;**10**(8):1723-38. doi: 10.21037/qims-19-1035. PubMed PMID: 32742963. PubMed PMCID: PMC7378088.
3. Leitgeb N. Comparative health risk assessment of electromagnetic fields. *Wien Med Wochenschr.* 2011;**161**(9-10):251-62. doi: 10.1007/s10354-011-0884-8. PubMed PMID: 21638216.
4. Maverakis E, Miyamura Y, Bowen MP, Correa G, Ono Y, Goodarzi H. Light, including ultraviolet. *J Autoimmun.* 2010;**34**(3):J247-57. doi: 10.1016/j.jaut.2009.11.011. PubMed PMID: 20018479. PubMed PMCID: PMC2835849.
5. Dale Wilson B, Moon S, Armstrong F. Comprehensive review of ultraviolet radiation and the current status on sunscreens. *J Clin Aesthet Dermatol.* 2012;**5**(9):18-23. PubMed PMID: 23050030. PubMed PMCID: PMC3460660.
6. Rivas M, Rojas E, Araya MC, Calaf GM. Ultraviolet light exposure, skin cancer risk and vitamin D production. *Oncol Lett*. 2015;**10**(4):2259-64. doi: 10.3892/ol.2015.3519. PubMed PMID: 26622830. PubMed PMCID: PMC4579804.
7. Bender T, Nagy G, Barna I, Tefner I, Kádas É, Géher P. The effect of physical therapy on beta-endorphin levels. *Eur J Appl Physiol.* 2007;**100**(4):371-82. doi: 10.1007/s00421-007-0469-9. PubMed PMID: 17483960.
8. Mbonimpa E, Blatchley E, Applegate B, Harper W. Ultraviolet A and B wavelength-dependent inactivation of viruses and bacteria in the water. *J Water Health*. 2018;**16**(5):796-806. doi: 10.2166/wh.2018.071. PubMed PMID: 30285960.
9. Yu SL, Lee SK. Ultraviolet radiation: DNA damage, repair, and human disorders. *Mol Cell Toxicol.* 2017;**13**:21-28. doi: 10.1007/s13273-017-0002-0.
10. Rünger TM, Farahvash B, Hatvani Z, Rees A. Comparison of DNA damage responses following equimutagenic doses of UVA and UVB: a less effective cell cycle arrest with UVA may render UVA-induced pyrimidine dimers more mutagenic than UVB-induced ones. *Photochem Photobiol Sci.* 2012;**11**(1):207-15. doi: 10.1039/c1pp05232b. PubMed PMID: 22005748.
11. Jensen MB. Vitamin D and male reproduc-

tion. *Nat Rev Endocrinol*. 2014;**10**(3):175-86. doi: 10.1038/nrendo.2013.262. PubMed PMID: 24419359.

12. Burgaz A, Orsini N, Larsson SC, Wolk A. Blood 25-hydroxyvitamin D concentration and hypertension: a meta-analysis. *J Hypertens.* 2011;**29**(4):636-45. doi: 10.1097/HJH.0b013e32834320f9. PubMed PMID: 21191311.
13. Panich U, Sittithumcharee G, Rathviboon N, Jirawatnotai S. Ultraviolet radiation-induced skin aging: the role of DNA damage and oxidative stress in epidermal stem cell damage mediated skin aging. *Stem Cells Int.* 2016;**2016**:7370642. doi: 10.1155/2016/7370642. PubMed PMID: 27148370. PubMed PMCID: PMC4842382.
14. De Jager T, Cockrell A, Du Plessis S. Ultraviolet light induced generation of reactive oxygen species. *Adv Exp Med Biol.* 2017;**996**:15-23. doi: 10.1007/978-3-319-56017-5_2. PubMed PMID: 29124687.
15. Schuch AP, Moreno NC, Schuch NJ, Menck CFM, Garcia CCM. Sunlight damage to cellular DNA: Focus on oxidatively generated lesions. *Free Radic Biol Med.* 2017;**107**:110-24. doi: 10.1016/j.freeradbiomed.2017.01.029. PubMed PMID: 28109890.
16. Tomkova M, Schuster-Böckler B. DNA modifications: naturally more error prone? *Trends Genet.* 2018;**34**(8):627-38. doi: 10.1016/j.tig.2018.04.005. PubMed PMID: 29853204.
17. Wang M, Gao Q, Teng X, Pan M, Lin T, Zhou G, et al. Ionizing radiation, but not ultraviolet radiation, induces mitotic catastrophe in mouse epidermal keratinocytes with aberrant cell cycle checkpoints. *Exp Dermatol.* 2018;**27**(7):791-4. doi: 10.1111/exd.13665. PubMed PMID: 29672918.
18. Ramasamy K, Shanmugam M, Balupillai A, et al. Ultraviolet radiation-induced carcinogenesis: Mechanisms and experimental models. *Journal of Radiation and Cancer Research*. 2017;**8**(1):4-19. doi: 10.4103/0973-0168.199301.
19. Lautenschlager S, Wulf HC, Pittelkow MR. Photoprotection. *Lancet.* 2007;**370**(9586):528-37. doi: 10.1016/S0140-6736(07)60638-2. PubMed PMID: 17693182.
20. Balogh TS, Velasco MVR, Pedriali CA, Kaneko TM, Baby AR. Ultraviolet radiation protection: current available resources in photoprotection. *An Bras Dermatol.* 2011;**86**(4):732-42. doi: 10.1590/s0365-05962011000400016. PubMed PMID: 21987140.
21. Serpone N, Dondi D, Albini A. Inorganic and organic UV filters: Their role and efficacy in sunscreens and suncare products. *Inorganica Chimica Acta*. 2007;**360**(3):794-802. doi: 10.1016/j.ica.2005.12.057.
22. Bairi VG, Lim JH, Fong A, Linder SW. Size characterization of metal oxide nanoparticles in commercial sunscreen products. *Journal of Nanoparticle Research*. 2017;**19**(7). doi: 10.1007/s11051-017-3929-0.
23. Smijs TG, Pavel S. Titanium dioxide and zinc oxide nanoparticles in sunscreens: focus on their safety and effectiveness. *Nanotechnol Sci Appl.* 2011;**4**:95-112. doi: 10.2147/NSA.S19419. PubMed PMID: 24198489. PubMed PMCID: PMC3781714.
24. Hossain MA, Rahman M. A review of nano particle usage on textile material against ultra violet radiation. *Journal of Textile Science and Technology.* 2015;**1**(03):93. doi: 10.4236/jtst.2015.13010.
25. Lu P, Fang S, Cheng W, Huang S, Huang M, Cheng H. Characterization of titanium dioxide and zinc oxide nanoparticles in sunscreen powder by comparing different measurement methods. *J Food Drug Anal.* 2018;**26**(3):1192-200. doi: 10.1016/j.jfda.2018.01.010. PubMed PMID: 29976411.
26. Lu PJ, Huang SC, Chen YP, Chiueh LC, Shih DYC. Analysis of titanium dioxide and zinc oxide nanoparticles in cosmetics. *J Food Drug Anal.* 2015;**23**(3):587-94. doi: 10.1016/j.jfda.2015.02.009. PubMed PMID: 28911719.
27. Baan R, Straif K, Grosse Y, Secretan B, El Ghissassi F, Cogliano V. Carcinogenicity of carbon black, titanium dioxide, and talc. *Lancet Oncol*. 2006;**7**(4):295-6. doi: 10.1016/s1470-2045(06)70651-9. PubMed PMID: 16598890.
28. Priyadarsini KI. Photophysics, photochemistry and photobiology of curcumin: Studies from organic solutions, bio-mimetics and living cells. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews*. 2009;**10**(2):81-95. doi: 10.1016/j.jphotochemrev.2009.05.001.
29. Barolet D, Christiaens F, Hamblin MR. Infrared and skin: Friend or foe. *J Photochem Photobiol B.* 2016;**155**:78-85. doi: 10.1016/j.jphotobiol.2015.12.014. PubMed PMID: 26745730. PubMed PMCID: PMC4745411.

30. Vandersee S, Beyer M, Lademann J, Darvin ME. Blue-violet light irradiation dose dependently decreases carotenoids in human skin, which indicates the generation of free radicals. *Oxid Med Cell Longev*. 2015;**2015**:579675. doi: 10.1155/2015/579675. PubMed PMID: 25741404. PubMed PMCID: PMC4337113.
31. Hatori M, Gronfier C, Van Gelder R, Bernstein P, Carreras J, Panda S, et al. Global rise of potential health hazards caused by blue light-induced circadian disruption in modern aging societies. *NPJ Aging Mech Dis.* 2017;**3**:9. doi: 10.1038/s41514-017-0010-2. PubMed PMID: 28649427. PubMed PMCID: PMC5473809.
32. Tosini G, Ferguson I, Tsubota K. Effects of blue light on the circadian system and eye physiology. *Mol Vis.* 2016;**22**:61-72. PubMed PMID: 26900325. PubMed PMCID: PMC4734149.
33. Chang AM, Aeschbach D, Duffy JF, Czeisler CA. Evening use of light-emitting eReaders negatively affects sleep, circadian timing, and next-morning alertness. *Proc Natl Acad Sci U S A.* 2015;**112**(4):1232-7. doi: 10.1073/pnas.1418490112. PubMed PMID: 25535358. PubMed PMCID: PMC4313820.
34. Ayaki M, Hattori A, Maruyama Y, Nakano M, et al. Protective effect of blue-light shield eyewear for adults against light pollution from self-luminous devices used at night. *Chronobiol Int*. 2016;**33**(1):134-9. doi: 10.3109/07420528.2015.1119158. PubMed PMID: 26730983.
35. Karami Z, Golmohammadi R, Heidaripahlavian A, Poorolajal J, Heidarimoghadam R. Effect of daylight on melatonin and subjective general health factors in elderly people. *Iran J Public Health.* 2016;**45**(5):636-43. PubMed PMID: 27398336. PubMed PMCID: PMC4935707.
36. Augood CA, Vingerling JR, De Jong PT, Chakravarthy U, et al. Prevalence of age-related maculopathy in older Europeans: the European Eye Study (EUREYE). *Arch Ophthalmol.* 2006;**124**(4):529-35. doi: 10.1001/archopht.124.4.529. PubMed PMID: 16606879.
37. Sklar LR, Almutawa F, Lim HW, Hamzavi I. Effects of ultraviolet radiation, visible light, and infrared radiation on erythema and pigmentation: a review. *Photochem Photobiol Sci.* 2013;**12**(1):54-64. doi: 10.1039/c2pp25152c. PubMed PMID: 23111621.
38. Mittermayr R, Osipov A, Piskernik C, Haindl S, Dungel P, Weber C, et al. Blue laser light increases perfusion of a skin flap via release of nitric oxide from hemoglobin. *Mol Med.* 2007;**13**(1-2):22-9. doi: 10.2119/2006-00035. Mittermayr. PubMed PMID: 17515954. PubMed PMCID: PMC1869628.
39. Stevens RG, Brainard GC, Blask DE, Lockley SW, Motta ME. Adverse health effects of nighttime lighting: comments on American Medical Association policy statement. *Am J Prev Med.* 2013;**45**(3):343-6. doi: 10.1016/j.amepre.2013.04.011. PubMed PMID: 23953362.
40. Wang X, Armstrong M, Cairns B, Key T, Travis R. Shift work and chronic disease: the epidemiological evidence. *Occup Med (Lond)*. 2011;**61**(2):78-89. doi: 10.1093/occmed/kqr001. PubMed PMID: 21355031. PubMed PMCID: PMC3045028.
41. Jarrett SG, Boulton ME. Consequences of oxidative stress in age-related macular degeneration. *Mol Aspects Med.* 2012;**33**(4):399-417. doi: 10.1016/j.mam.2012.03.009. PubMed PMID: 22510306. PubMed PMCID: PMC3392472.
42. Koushan K, Rusovici R, Li W, Ferguson L, Chalam K. The role of lutein in eye-related disease. *Nutrients.* 2013;**5**(5):1823-39. doi: 10.3390/nu5051823. PubMed PMID: 23698168. PubMed PMCID: PMC3708350.
43. Stevanato R, Bertelle M, Fabris S. Photoprotective characteristics of natural antioxidant polyphenols. *Regul Toxicol Pharmacol.* 2014;**69**(1):71-7. doi: 10.1016/j.yrtph.2014.02.014. PubMed PMID: 24607767.
44. Wang Y, Zhao L, Huo Y, Zhou F, Wu W, Lu F, et al. Protective effect of proanthocyanidins from sea buckthorn (Hippophae rhamnoides L.) seed against visible light-induced retinal degeneration in vivo. *Nutrients.* 2016;**8**(5):245. doi: 10.3390/nu8050245. PubMed PMID: 27144578. PubMed PMCID: PMC4882658.
45. Jiao L, Zhang X, Huang L, Gong H, Cheng B, Sun Y, et al. Proanthocyanidins are the major anti-diabetic components of cinnamon water extract. *Food Chem Toxicol.* 2013;**56**:398-405. doi: 10.1016/j.fct.2013.02.049. PubMed PMID: 23499750.
46. Solano F. Melanin and melanin-related polymers as materials with biomedical and biotechnological applications—Cuttlefish ink and mussel foot proteins as inspired biomolecules. *Int J Mol Sc*i. 2017;**18**(7):1561. doi: 10.3390/ijms18071561. PubMed PMID: 28718807. PubMed PMCID:

PMC5536049.

47. Qureshi MR, Alfadhl Y, Chen X, Peyman A, Maslanyj M, Mann S. Assessment of exposure to radio frequency electromagnetic fields from smart utility meters in GB; part II) numerical assessment of induced SAR within the human body. *Bioelectromagnetics*. 2018;**39**(3):200-16. doi: 10.1002/bem.22094. PubMed PMID: 29143352.
48. Moradi M, Naghdi N, Hemmati H, Asadi-Samani M, Bahmani M. Effect of ultra high frequency mobile phone radiation on human health. *Electron Physician*. 2016;**8**(5):2452-7. doi: 10.19082/2542. PubMed PMID: 27382458. PubMed PMCID: PMC4930268.
49. Yakymenko I, Tsybulin O, Sidorik E, Henshel D, Kyrylenko O, Kyrylenko S. Oxidative mechanisms of biological activity of low-intensity radiofrequency radiation. *Electromagn Biol Med.* 2016;**35**(2):186-202. doi: 10.3109/15368378.2015.1043557. PubMed PMID: 26151230.
50. Buchner K, Eger H. Changes of clinically important neurotransmitters under the influence of modulated RF fields—a long-term study under real-life conditions. *Umwelt-Medizin-Gesellschaft.* 2011;**24**(1):44-57.
51. Hosseini M, Hosseini A, Jarideh S, Argasi H, et al. Evaluating Short-Term Exposure to Wi-Fi Signals on Students'reaction Time, Short-Term Memory and Reasoning Ability. *Radiat Prot Dosimetry.* 2019;**187**(3):279-85. doi: 10.1093/rpd/ncz162. PubMed PMID: 31251356.
52. Ghadimi-Moghadam A, Mortazavi SMJ, Hosseini-Moghadam A, et al. Does exposure to static magnetic fields generated by magnetic resonance imaging scanners raise safety problems for personnel? *J Biomed Phys Eng.* 2018;**8**(3):333-6. PubMed PMID: 30320037. PubMed PMCID: PMC6169123.
53. Jarideh S, Taeb S, Pishva S, Haghani M, Sina S, Mortazavi S, et al. Does occupational exposure of Shahid Dastghieb International Airport workers to radiofrequency radiation affect their short term memory and reaction time? *J Biomed Phys Eng.* 2015;**5**(3):143-50. PubMed PMID: 26396970. PubMed PMCID: PMC4576875.
54. Van Deventer E, Van Rongen E, Saunders R. WHO research agenda for radiofrequency fields. *Bioelectromagnetics.* 2011;**32**(5):417-21. doi: 10.1002/bem.20660. PubMed PMID: 21404307.
55. Manna D, Ghosh R. Effect of radiofrequency radiation in cultured mammalian cells: A review. *Electromagn Biol Med.* 2016;**35**(3):265-301. doi: 10.3109/15368378.2015.1092158. PubMed PMID: 27053138.
56. Burlaka A, Tsybulin O, Sidorik E, Lukin S, et al. Overproduction of free radical species in embryonal cells exposed to low intensity radiofrequency radiation. *Exp Oncol.* 2013;**35**(3):219-25. PubMed PMID: 24084462.
57. Blank M, Goodman R. DNA is a fractal antenna in electromagnetic fields. *Int J Radiat Biol.* 2011;**87**(4):409-15. doi: 10.3109/09553002.2011.538130. PubMed PMID: 21457072.
58. Zhi WJ, Wang LF, Hu XJ. Recent advances in the effects of microwave radiation on brains. *Mil Med Res.* 2017;**4**(1):29. doi: 10.1186/s40779-017-0139-0. PubMed PMID: 29502514. PubMed PMCID: PMC5607572.
59. Fattahi-asl J, Baradaran-Ghahfarokhi M, Karbalae M, Baradaran-Ghahfarokhi M, Baradaran-Ghahfarokhi HR. Effects of radiofrequency radiation on human ferritin: An in vitro enzymun assay. *J Med Signals Sens.* 2012;**2**(4):235-40. PubMed PMID: 23724375. PubMed PMCID: PMC3662108.
60. Kıvrak EG, Yurt KK, Kaplan AA, Alkan I, Altun G. Effects of electromagnetic fields exposure on the antioxidant defense system. *J Microsc Ultrastruct.* 2017;**5**(4):167-76. doi: 10.1016/j.jmau.2017.07.003. PubMed PMID: 30023251. PubMed PMCID: PMC6025786.
61. Maskey D, Kim M, Aryal B, Pradhan J, et al. Effect of 835 MHz radiofrequency radiation exposure on calcium binding proteins in the hippocampus of the mouse brain. *Brain Res.* 2010;**1313**:232-41. doi: 10.1016/j.brainres.2009.11.079. PubMed PMID: 19968972.
62. Sage C, Burgio E. Electromagnetic fields, pulsed radiofrequency radiation, and epigenetics: How wireless technologies may affect childhood development. *Child Dev.* 2018;**89**(1):129-36. doi: 10.1111/cdev.12824. PubMed PMID: 28504324.
63. Chou C. A need to provide explanations for observed biological effects of radiofrequency exposure. *Electromagn Biol Med.* 2015;**34**(3):175-9. doi: 10.3109/15368378.2015.1076439. PubMed PMID: 26444189.
64. Hardell L. World Health Organization, radiofre-

quency radiation and health-a hard nut to crack. *Int J Oncol.* 2017;**51**(2):405-413. doi: 10.3892/ijo.2017.4046. PubMed PMID: 28656257. PubMed PMCID: PMC5504984.

65. Mahmoudi A, Shojaeifard M, Nematollahii S, Mortazavi S, Mehdizadeh A. Effect of microwave wi-fi radiation at frequency of 2.4 GHz on epileptic behavior of rats. *J Biomed Phys Eng.* 2018;**8**(2):185-192. PubMed PMID: 29951445. PubMed PMCID: PMC6015645.

66. Mehdizadeh AR, Mortazavi SMJ. 5G Technology: Why Should We Expect a shift from RF-Induced Brain Cancers to Skin Cancers? *J Biomed Phys Eng*. 2019;**9**(5):505-6. doi: 10.31661/jbpe.v0i0.1225. PubMed PMID: 31750263. PubMed PMCID: PMC6820018.