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Review Article

Ionizing and non-ionizing electromagnetic radiation in modern medicine

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ABSTRACT

Introduction: Electromagnetic radiation (EMR) has been successfully employed in modern medicine for many years. The medical community, however, often lacks in-depth knowledge concerning different types of radiation, their mechanisms of action and clinical applications.

Aim: Our review offers a comprehensive overview of the biological action of ionizing radiation (IR) and non-ionizing radiation (NIR) and their applications in modern medicine. Chronic exposure to a high frequency electromagnetic field (EMF) as a potential public health risk is also discussed.

Materials and methods: Current literature on IR and NIR has been reviewed and grouped thematically.

Results and discussion: Biological effects of EMR depend on its physical properties. IR is a potentially lethal stream of high energy particles. NIR carries less energy. EMR can damage DNA directly or indirectly via reactive oxygen/nitrogen species. It has been, however, successfully used in oncology (radiotherapy), physiotherapy (microwaves), rheumatology and endocrinology. Effective communication and data transmission are possible thanks to radio-, micro- and infrared waves. Cybernetics and modern forms of communication have been instrumental in the development of telerehabilitation and telemedicine. Evidence for the detrimental effects of cell phones, the most common source of EMR, on the developing central nervous system is scarce, but concerns have been raised about their carcinogenicity.

Conclusions: Modern medicine cannot function without IR and NIR. However, their potentially undesirable biological side effects need to be taken into account.

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1. Introduction

Biological effects of electromagnetic radiation (EMR) vary depending on its physical properties and, in particular, ionizing potential. They have been described in greater detail in part I of our review.

Ionizing radiation (IR) creates a stream of high-energy photons or alpha particles, protons and neutrons which in high doses can be lethal to living organisms.[18,42,43] Acute postradiation syndrome triggered by excessive IR often leads to organ failure or death. Early changes include lymphocytes deficiency, impaired cellular immunity, anemia, transient infertility, acute radiation dermatitis, hair loss, lens opacity, and acute intestinal inflammation. Long-term (late) effects may lead to malignancies including leukemia.[41,43]

A relatively low energy non-ionizing radiation (NIR) does not cause lethal ionization of atoms and molecules of matter.[18,27,37]

On entering the body, IR and NIR damage nitrogenous bases of the deoxyribonucleic acid (DNA) directly or indirectly through reactive oxygen species (ROS) or nitrogen species (RNS). ROS (free radicals) include hydroxyl ($OH^{\bullet}$), hydroperoxide ($HO_2^{\bullet}$) and superoxide ($O_2^{\bullet -}$) radicals, hydrogen peroxide H_2O_2 and singlet oxygen ($^1O_2$) (Fig. 1).

$OH^{\bullet}$ produced in the Fenton reaction are the most reactive of all ROS. $HO_2^{\bullet}$ and $O_2^{\bullet -}$ have a long half-life, but are rare. They can, however, transform into highly reactive $OH^{\bullet}$ radicals in the iron-catalyzed Haber–Weiss reaction. RNS family encompasses nitric oxide (NO) and its metabolites: nitrosonium cation (NO^+), nitroxyl anion (NO^-) and peroxynitrite ($ONOO^-$). Oxidative DNA damage is induced mainly by hydroxyl radicals; $O_2^{\bullet -}$ and H_2O_2 do not cause direct DNA changes. H_2O_2 penetrates easily into the nuclear membrane of the nucleus and becomes a substrate in the Fenton reaction, producing highly damaging $OH^{\bullet}$. Interaction of $OH^{\bullet}$ with DNA damages deoxyribose, breaks phosphodiester bonds between nucleotides and cross-links with nuclear proteins and DNA. Interaction of hydroxyl radicals with deoxyribose residues in turn breaks single or double-stranded DNA.

Hydroxyl radicals alter amino acid residues and prosthetic groups of enzymes and cause fragmentation and aggregation of proteins. Proteins with aromatic amino acids and sulphur (cysteine, methionine, etc.) are the most susceptible. ROS and RNS contribute to lipid peroxidation, change physicochemical properties of cell membranes and their liquidity and disturb transmembrane transport in the respiratory chain and intracellular signal transduction.[7,17,20,34,37,38]

In cancerous cells, ROS and lipid peroxidation products act directly on the nuclear transcription factor κB (NF-κB; REL oncogene family) and alter the expression of Bcl-2, Bax and p53. These molecules regulate apoptosis and the rate of telomerase shortening and inhibit the growth and apoptosis of malignant cells. In healthy cells, ROS activate oncogenes and inactivate tumor suppressor genes, which may initiate carcinogenesis and tumor progression.[8,12,20,28,33,42]

2. Aim

Our review endeavors to familiarize healthcare professionals with the biological action of IR and NIR and their ever

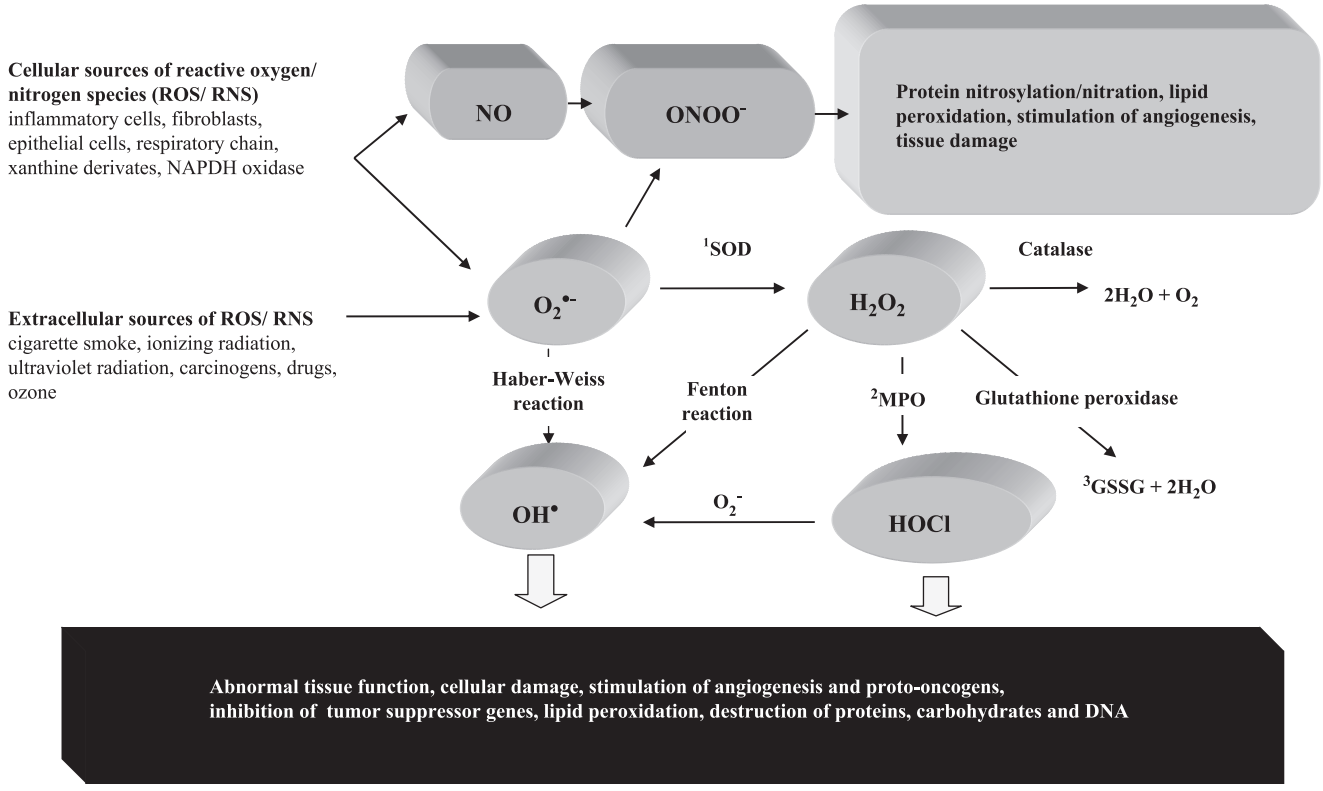

Fig. 1 – Reactive oxygen and nitrogen species (ROS/RNS) – mechanism of action:[34] ^{1}SOD – superoxide dismutase, ^{2}MPO – myeloperoxidase, ^{3}GSSG – glutathione disulfide.

expanding application in modern medicine. Chronic exposure to a high frequency electromagnetic field (EMF) as a potential public health risk is also discussed.

3. Materials and methods

Current literature on IR and NIR has been reviewed and grouped thematically.

4. Results and discussion

4.1. *Biological effects and medical application of IR*

The universe, the sun as well as many radioactive elements (U^{238}, Th^{232}) are the main natural sources of IR. It is also produced in a nuclear chain reaction; extraction and processing of radioactive ores; production of nitrogen fertilizers; extraction of gas and oil and as a result of military nuclear explosions.[18,22] Artificial sources of IR include X-ray machines, computed tomographs (CT) and positron emission computed tomographs (PECT), radiosurgical tools (Gamma Knife, CyberKnife) and sterilizers for tissue grafts or polymeric single-use medical devices. IR might also be emitted by ultraviolet lamps.[3,4,11,22] IR is effective in the therapy of many malignant tumors, osteoarthritis of the hip and knee, painful shoulder syndrome, periarthritis of the elbow, calcaneal spurs, hyperthyroidism and exophthalmos in Graves' disease, keloids, age-related macular degeneration, and many other benign disorders.[3,21,44,45]

4.2. *Biological effects and medical application of NIR*

NIR includes all components of the electro-magnetic spectrum with the vibration frequency being lower than gamma rays and part of the ultraviolet radiation.[19,22,25,27,31,32] The sun is a natural source of NIR. Man-generated sources include[9,13,14,18,22,27,35,40] power grid and power transmission networks, television and radio transmitters, cellular radio base stations, microwave ovens, computer monitors and television, wireless routers, cordless phones, batteries, cell phones, wireless fidelity (WiFi; wireless transmission of information systems based on radio technology for high frequency), worldwide interoperability for microwave access (WiMAX; a global system for wireless microwave data transmission), digital enhanced cordless telecommunication (DECT; enhanced wireless digital telecommunications), personal handy-phone system (PHS; a system of personal wireless mobile telephony), and radio-frequency identification device (RFID; control based on radio waves).

Medical electronic devices used to generate infrared, visible and/or ultraviolet light include quartz, quartz–mercury, mercury–steam, tungsten, xenon arc, and fluorescent lamps, light emitting diodes (LED) and dry or far infrared saunas (FIRS).[2,6,15,26,30,39]

4.3. *Biological effects and medical application of radio and microwaves*

Long electromagnetic waves (EMWs) of low frequencies penetrate deep into the body, while the majority of millimeter wave (MMW) energy precipitates in the tissue. The eye and testis are particularly sensitive to heating by radiofrequency (RF) energy, because of the relative lack of available blood flow to dissipate the excessive heat. Body water strongly suppresses the propagation of EMWs. Hence, highly hydrated tissues, like muscles and blood, are most vulnerable to MMWs which cause ionic vibration in electrolytes and dielectrics cell. This produces significant amounts of thermal energy. A temperature of 45–50°C alters cellular structure and function by dehydration, compaction, denaturation of proteins and destruction of cell membranes. In clinical practice this allows for thermal ablation of tumors and a MMW treatment of pharmacotherapy-resistant menorrhagia.[5,9,10,36] Microwaves (MWs) pass easily through poorly hydrated adipose tissue, but are strongly absorbed in muscles. Therefore, MW diathermy is used to treat muscle and tendon injuries.[10] Non-thermal action of the power-frequency (ELF) and RF/MW causes biological damage not only by heating, but also through inducing intracellular free radicals. High EMF/RF exposure disturbs membrane function, cellular communication and metabolism, activates proto-oncogenes and triggers stress proteins. This leads to DNA breaks and chromosomal aberrations, apoptosis, increased production of free radicals, activation of the endogenous opioid system, cellular stress and causes premature aging, neurological impairment and, in some cases, initiation of carcinogenesis.[14,35] Conversely, low levels of MMWs in animals and humans have been reported to activate tissue repair and regeneration, alleviate stress reaction and stimulate the immune system. MMWs also increase phagocytosis in macrophages, natural killer cell cytolytic activity, expression of CD69 molecules, B-cells and the production of TNF-α and IFN-γ. These immunostimulatory effects have been long used in Eastern Europe to treat gastric, cardiac, pulmonary and dermatological disorders.[1,23,24,29]

4.4. *Potential public health risks of chronic exposure to EMF of high frequencies*

Man-generated EMR is omnipresent in everyday life, industry and medicine and creates "electronic smog." The widespread use of mobile telephony has stimulated the discussion on its potentially negative effects on the human body. There is scarce evidence concerning the harmful effects of mobile phones on the central nervous system, but concerns have been raised about potentially carcinogenic effects of the radiation emitted by phone batteries. Children are of particular concern in this respect.[14,16,35] Two decades of this astounding information technology revolution have not been long enough to determine whether mobile phones, Global Positioning System (GPS), WiFi connectivity, radiology diagnostic tools (MRI, PET, SPECT) or radiosurgical operating systems are indeed associated with an increase in adverse health outcomes. Just as with tobacco smoking, a significantly longer period of clinical observation may be required to confirm or refute the deleterious effect of radiation and EMF on humans. There is, therefore, an urgent need for further in-depth studies concerning the risk of cancer in people exposed to a constant EMF. Until more extensive and reliable data are available, special care is recommended,

particularly for children, who are more prone to the harmful effects of EMF than adults. Limiting the number of electronic devices in children's immediate environment may be warranted.

5. Conclusions

It is now evident that modern medicine cannot function without IR and NIR. However, their potentially undesirable biological side effects need to be taken into account.

Conflict of interest

None declared.

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