Radiofrequency Fields (RF) and their Biological Effects

Introduction

In the physical realm, matter and energy interact with each other in many forms and levels. Of particular interest to biology is how electromagnetic energy interacts with matter, especially organic matter, and how this affects in any way the form and function of living cells, tissues and organisms. For the health sciences, these interactions may have interest for its detrimental effects on organisms, particularly human beings.

In the last 100 years, a great deal of scientific research has discovered and studied the nature and properties of electromagnetic radiation and how it interacts with matter in general, and living matter in particular. The visible part of the electromagnetic spectrum, which was the only one known by Man until the last quarter of the 19th century, has been studied for a number of such interactions. In fact, life forms are mostly possible on Earth only because of these interactions, such as photosynthesis. With the discovery of other forms of electromagnetic energy, such as x-rays, gamma rays and ultraviolet, all of which are non-visible to the human eye, other mechanisms and effects of energy-matter interaction were discovered. For instance, the detrimental nature of x-rays to molecules, cells and organisms was discovered only when radiologists began to develop malignant skin diseases after extensive and prolonged exposure to x-rays in the beginning of the 20th century, leading to the scientific study on the nature of these effects, and to the elucidation of its genotoxic potential (such as inducing mutations in the genetic material of cells, cell death, etc.).

As a consequence of these studies, science has determined that, with regard to its effects on atoms, molecules and its bonds, the electromagnetic spectrum can be roughly divided into two types.

1) frequencies that possess enough energy to remove electrons of the outer orbitals of some atoms, thus rendering then into ions (charged atoms called ions), a process which is called ionization; and

2) frequencies that do not have enough energy to produce ionization, and that interact with matter in other forms, such as producing mechanical vibration of atoms, which is expended as thermal energy.

Accordingly, electromagnetic energy has been classified into ionizing and non-ionizing radiation, which has been somewhat in an overly simplified way associated to frequency alone, which is wrong, since the ionization potential depends not only on frequency but also on the properties of matter which it impinges upon, specifically the vulnerability of molecular bonds to ionization. For example, photosynthesis depends on an ionization step, caused by yellow light, which is generally considered as a non-ionization frequency, as well as the effects of light on melatonin in the skin, the synthesis of vitamin D, the primary molecular mechanism of vision, and several others.

Natural and Artificial Sources

Electromagnetic energy is found everywhere in the Universe, and has many natural sources for Earth-bound life forms, such as the Sun itself (by far the largest one, particularly for visible light, but also for other frequencies as well), other stars (x-ray and cosmic radiation) and planets (radio waves), the magnetosphere of the Earth, etc. In fact, any body at a given temperature emits some EMF energy, including our own bodies.

In the last century, with the discovery of practical applications and novel devices that use electromagnetic energy, such as x-ray tubes, gamma ray sources for medical treatment, infrared and radio communicators, lasers, electrical transmission lines, motors and dynamos, electromagnets, electronic devices, etc, the environment where we live has been gradually and increasingly “invaded” by artificial sources that superimpose on the natural electromagnetic sources. Most of them, being invisible and with unknown interaction properties with living matter began to generate a fear of possible detrimental effects on health. This fear is a natural response and has happened with practically all new technologies, such as the telegraph, the telephone, the television, the computer, the cell phone, and so on.

The intensities of emissions of these artificial sources vary a lot: they can be extremely high (such as microwave ovens, high-power lasers and masers, or near long-range radio communication or radar antennas) to the extremely low (such as in geosynchronous satellite communication and short range data communication devices, like the Bluetooth technology). Thus, some can have obvious detrimental effects, such as the cooking of biological matter by microwave ovens, while others appear to have no effect at all, such as the small wireless signal we use to open garage doors.

More recently, due to the enormous growth of wireless mobile communication, especially cell phones, worry about the possible effect of such mass implementation of radio base stations and the use of handheld devices began to appear, leading to the increase in scientific investigation on whether non-ionizing radiation (NIR) used in these technologies could have short-, medium- or long-term biological effects, and whether they could represent a health hazard to human populations. In fact, any detectable detrimental effect, even small, could be very important, due to its widespread use, the monumental numbers of people exposed to NIR on a daily basis, and the social, economical and health impacts this could have.

This research began to appear in significant numbers in the 1970s, and has grown exponentially since then, generating an enormous body of published information. Learned societies and governmental and international committees, agencies and groups were formed to examine the subject and have produced also a great number of technical reports and recommendations, which have been updated regularly for many years. Large scale cooperative multi-country research efforts have also been initiated and a great deal of work and financial and human resources have been applied to these efforts. All this immense effort, which has much larger funds than many other diseases, is fueled by the public apprehension (especially in developed countries) and the need to institute standards of protection and precautionary measures, or to introduce government-mandated regulation and limitations to the spread and use of man-made EMF sources.

Rationale for this Review

Although many competent and exhaustive reviews of the literature on the biological and health effects of non-ionizing electromagnetic fields have been published worldwide recently (*e.g,* ICNIRP, 2009), we have many reasons to believe that a new literature review conducted by Latin American experts in the field is justified to give a regional perspective on this issue.

Firstly, although there is a small body of research carried out in this area in Latin American countries, it is important to bring them to light and to review and discuss their findings. Some of these regional contributions might provide a significant contribution to the overall body of knowledge, since they reflect social, environmental, professional or technical particularities of Latin American countries.

Secondly, there are nowadays in the region many growing concerns about the possible health effects of NIR in human populations exposed to it, mainly due to the explosive growth of wireless mobile communication and data networks in Latin America in the last decade. In a recent statistical report, it has been stated that:

> "*Mobile penetration in Latin America and the Caribbean was approximately 80% in early 2009, well above the world average which was about 58%. With 458 million people owning a mobile phone in early 2009, Latin America and the Caribbean together hold approximately 12% of the world's 3.97 billion mobile subscribers. Several countries, including Brazil, Argentina, Jamaica, Uruguay, and Venezuela have passed the "100% penetration threshold*" (Latin America Mobile Communication Statistics, May 2009). According to a GSM Alliance Report, "*Latin America and the Caribbean led the world market percentage growth rate for GSM, adding more than 74 million new customers in the one year period from March 2005 to March 2006, nearly doubling their subscriber base with a growth rate of 97%*"

This fear has been pervading in all social and economical classes, despite the extensive use of cell phones by the population, and is fueled often by reports in the lay press that reproduce, in a non critical way, what the international press publishes. In addition, a widespread call to restrictive legislation by politicians has produced many laws that are not solidly supported by scientific evidence, and which has been causing more harm than good. Thus, the examination and the expert opinion of Latin American scientists is important and adds an all-important factor of trust. Besides, Latin American scientists are obviously more aware of the particularities of NIR use, legislation and enforcement of regulations, etc. in the region.

Therefore, the literature review was carried out with these purposes and approaches in mind, and as often as possible we will review Latin American contributions to the body of research, and issue recommendations in regard to its importance, applicability and viability in Latin American countries.

In order to find relevant and high quality papers published in this field in Latin America we have researched three literature databases: 1) the LILACS (*Literatura Latino Americana em Ciências da Saúde*, maintained by the Regional Center of Health Information for Latin America and the Caribbean, an agency of the Pan American Health Organization, which concentrates on journals published in the region.; 2) MEDLARS literature database of the

US National Library of Medicine, and 3) The EMF-WHO (*World Health Organization Electromagnetic Fields and Health Programme*) research database. The search strategy was using the names of Latin American countries in conjunction with proper keywords. Papers and books published by scientists and technicians of Latin American origin but working in countries not in the region were not considered.

Limitation of Scope

With the above in mind, the literature review and critical analysis that follows will limit its scope to the biological and health effects of non-ionizing electromagnetic radiation (jointly called **bioeffects**), limiting it to the frequency ranges used for radio and microwave communication, such as that used in radio and TV broadcasting, mobile voice and data communication, wireless data communication networks, etc.

We cover in the review not only the possible effects of occupational and general public exposure to these radiofrequency (RF) fields, but also direct and indirect effects of RF (such as the effects on medical devices). The review will not deal with other less relevant NIR sources, such as higher power sources of RF, light and infrared or with extremely low frequencies (ELF), such as in alternating current electrical power transmission.

Biological Effects of Non-Ionizing Radiation

The traditional and most effective approach to study cause-effect relationships in the biological sciences is by experimentation with cells and organisms. **Radiobiology** is the field of biological sciences that tries to elucidate how the several forms of radiation interact with and affect living beings of all kinds. **Bioelectromagnetics** is the sub-field of radiobiology that focuses on the study of electromagnetic fields, both ionizing and non-ionizing, be it naturally or artificially generated. It can be pure or applied research, but most of the applied research has as its target the eventual applicability of the acquired knowledge to human matters, such as the vulnerability to externally applied RF generated by devices, such as TV transmitters and cell phones.

In this section we will review the experimental evidence gathered on the biological effects of high frequency electromagnetic energy, particularly in the radio and microwave frequency range, carried out in many *in vitro and in vivo* models except human beings; this will be covered in the next chapter. This chapter includes *in vitro* (cell cultures and isolated tissues) or *in vivo* (living animals), particularly mammals, which are genetically and physiologically more similar to human beings than bacteria, worms or insects. In this way it is hoped that this knowledge can be transferred to human beings, who, for ethical reasons, cannot be used for most kinds of experiments.

In vitro models have been extensively used for studying non-ionizing electromagnetic field interactions at the level of molecules and the chemical machinery of life that works at these levels. They include cell and tissue metabolism, biochemical pathways and cascades, ion transport across membranes and inside cells, cellular division and growth, the entire system of genes, genetic expression, synthesis of proteins, codification and translation of information, DNA, RNA, enzymes, and many others. Theoretically, every single aspect of this immense and complex cellular works can be investigated in relation to RF. An important caveat, however, is that effects discovered at molecular or cell level do not automatically mean that they are relevant to abnormal functioning or to have consequences to health of the entire organism (D'Inzeo, 2009, Repacholi, 1998).

In vivo models used for experimentation with RF have been centered mostly on mammals, particularly laboratory-bred rodents, such as rats and mice. There are many advantages in using these species: they have more than 70% of their genes in common with *Homo sapiens*, are warm-blooded mammals, with similar physiology and biochemical systems, are easy to breed and maintain, have a relatively short life span and high reproduction rate (ideal for lifetime and genetic studies) and can be as genetically homogenous as one wishes, including strains that are genetically programmed to be highly susceptible to cancer and other diseases.

In regard to the ability to transfer or to apply the knowledge gained by way of experimenting with them, this is more difficult. For one thing, rats and mice are small, so radiation absorption and propagation are different from humans, including into the sensory organs, brain and hematopoietic systems, which are protected very little from external radiation by its thin bones. Furthermore, the biology of rodents is entirely the opposite of primates in general: since they are mainly nocturnal and underground dwelling, and so they have little protection developed by evolution against solar and other kinds of radiations. This can make them more sensitive to EMF than *Homo sapiens*. In addition, the behavioral biology, memory and cognitive abilities cannot be easily extrapolated to humans.

The freedom of performing systematic experimentation with living cells or organisms allow for extensive data gathering and the variation of many parameters, such as using several RF power densities, for example, in many different exposure schemes. A larger number of variables can be studied simultaneously or in isolation. In one example of the experimental exposure studies with rats, 151 physiological and clinical variables were recorded. The number of subjects in animal exposure studies is usually higher than those used in human experimentation, but is far less than in human epidemiological studies.