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Review Article

Wifi and health: Perspectives and risks

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Abstract

Increased exposure to electromagnetic fields such as radio frequencies used by Wifi technology raise questions and concerns about their impact on health. For answer these questions, several scientific studies have carried out followed by results publication in prestigious scientific revues. Literature conducted on the effects of non-ionizing radiation and Wifi waves is vast and sometimes controversial. Epidemiological studies and the results of in vitro and in vivo experimental studies have showed the biological effects of electromagnetic field in different frequencies range. These effects caused disorders at the molecular and behavioral level. However, these studies were insufficient to confirm the directly related effects to the cause. Therefore, further research must be done to raise the controversy about the safety of wireless waves.

Introduction

The evolution of the information society and the use of new technologies make the magnetic field omnipresent in all areas of life. Increased exposure to this type of field raise questions and concerns about their impact on health. Invading magnetic fields application in industries (radars, telecommunications...) and medecine (IRM) increase general and professional exposure. Therefore, international regulation is required. In fact, associations in France and abroad are concerned about the health effects of electromagnetic radiation. These associations relay the concerns of citizens, alert the authorities and seize the courts to enforce the precautionary principle [1]. within this context that the International Radiation Protection Committee (INC) has prepared recommendations on exposure limits for main types of non-ionizing radiation [2]. On the occasion of its 8th International Congress in Montreal (1992), the International Association of Radio Protection (IRPA) has set up a new independent scientific organization, International Commission for the Protection against Non-Ionizing Radiation Protection (ICNIRP) which takes over from the IRPA / INIRC. This commission's role is to study the potential risks associated with various forms of non-ionizing radiation and studying the protection against radiation.

Many scientific studies have already been conducted on the health risks of radiation and electromagnetic waves. Barnothy [3], is the first to have conducted a review on the biological effects of electromagnetic fields followed by other works [4-8]. The laboratory of «physiologie intégrée» in «Faculté des Science de Bizerte » (Tunisia) was also interested in the effects of electromagnetic waves on biological systems. de Chater et al. [9], have showed that the static magnetic field induces oxidative stress and apoptosis in the thymus cells of pregnant rats. Moreover, Abdelmelek et al. [10], reported that the static magnetic field (128 mT, 5 days) induces hypoxia-like associated with sympathetic hyperactivity proving that the CM could be considered an environmental stress agent. Similarly, Amara et al. [11], showed that subchronic exposure to the CMS induced oxidative stress and DNA fragmentation after cell leakage zinc accompanied by a decrease in antioxidant activity of the enzyme system such as glutathione peroxidase and catalase. Other studies showed that subacute exposure to CMS (128 mT) caused metabolic disorders, hyperglycemia and insulin decrease

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like diabetes state [12-14]. It was able to extend the lifetime of free radicals and to change the some enzymes activity [15,16]. These biologic changes depend on waves/matter interaction at considered frequency. It is known that electromagnetic fields permanently immersed in a frequency ocean from low frequency (between 0 static fields and 100 KHz high-tension lines and domestic installation) to radio frequency (100 KHz and 300 KHz: television, microwave oven etc.). In this revew, we reported the biological effects of waves generated by WIFI technology. This is a wireless network technique for short-distance data exchange by microwave fields (RF) at 2.45 GHz. Since WiFi are electromagnetic waves, specifically radio frequency (RF), we thought that it too could induce metabolic disorders. There are few scientific studies on the physiological effects of WiFi as a recent technology. Most existing scientific studies support their hypotheses and thoughts on epidemiological studies on the effects of these RF on neurophysiology [1,17,18]. The biological effects of RF could be attributed to their thermal and non-thermal effects on health causing the appearance or development of pathologies. In fact, the RF could increase the production of free radicals and cause metabolic disorders such as diabetes [19,20].

Electromagnetic waves

For many years, Electromagnetic fields are a source of questions for the. Concerns were initially focused on power lines before moving recently to the antennas of mobile telephony. To answer these questions, thousands of scientific studies were launched, followed by the results published in prestigious scientific journals [5,6,16]. The use of electromagnetic fields has expanded to gradually gain industry, the medical field, homes and recently wireless transmission technologies that have invaded the High-Tech market (mobile phone, radio identification). Among these technologies, the WiFi is expanding rapidly and generates controversy. In fact, the use of the mobile phone generated a climate of suspicion about potential health risks of WiFi technology [21].

Definition of electromagnetic field

There is an electric field around every electrical installations caused by the electric charge transport due to the presence of an electric potential difference. The intensity of the created field depends on the voltage. Indeed, the magnetic field is the result from current produced by charges movement [22]. Therefore, Electromagnetic fields are the result of the combination of both electric and magnetic fields which move together with the speed of light. It are characterized by their frequency (hertz: Hz) and their wavelength [23].

Physical quantities and units

Magnetic field is characterized by the magnetic flux density (B), expressed in Tesla (T), and the magnetic field strength (H) expressed in Amperes per meter (A.m-1): $B=\mu*H$

μ represents the physical constant of proportionality (magnetic permeability) (Institut National de Recherche et de Sécurité, 2011). Table 1 Quantities and SI units [24].

Table 1: Quantities and SI units [24].

Quantity	Symbol and Unit
Electric field strength	E (V/m)
Electrical conductivity	σ (S/m)
Magnetic field strength	H (A/m)
Frequency	F or v (Hz or s−1)
Magnetic flux density	B (T)
Permeability	μ (H/m)
Permittivity	E (F/m)
Power density	S (W/m2)
wave length	λ (m)
Specific Absorption Rate	DAS (W/kg)

Sources of electromagnetic waves

Electromagnetic waves are emitted from two types of sources:

- Natural source

  In our environment, we found Earth's electromagnetic field generated by solar and atmospheric activities. This is a static magnetic field (25-65 microT). In fact, the orientation of the magnetic compass needle in the north-south direction is due to the Earth's magnetic field. This field guides birds and fish during their migrations. In addition, the human body and specifically the heart and brain cells also produce low power electric and magnetic fields [25].

- Artificial sources

  Electrical devices and modern communication generate electromagnetic waves such as microwave ovens, radios, television sets, magnetic resonance imaging, mobile phones and power lines [26,27]. Figure 1 electromagnetic spectrum and sources of non-ionizing and ionizing radiation (Federal office for radiation safety, Germany, 1999).

Electromagnetic spectrum

The electromagnetic spectrum is the decomposition of the electromagnetic radiation according to its different components (frequency, wavelength). Only a small portion of the spectrum is visible to the human eye called visible light. The properties of electromagnetic waves depend on their energy amount. X and gamma rays have the highest frequencies, followed by ultraviolet, visible light (red to violet), infrared, radio frequency or microwave s and extremely low frequencies [28].

Electromagnetic field properties

Magnetic waves are characterized by several physical parameters including:

- The electric field intensity (E),
- The magnetic field intensity (H),
- The magnetic flux density (B),
- The power density (S),

Figure 1: Electromagnetic spectrum and sources of non-ionizing and ionizing radiation (Federal office for radiation safety, Germany, 1999).

The variables related to perception and other indirect effects are contact current and, specific absorption (SA) (for pulsed fields). These quantities are used to define two limit values which are represented by:

- Basic restriction: limit values for exposure to electric, magnetic or electromagnetic at variable frequency. These values are established directly from the health effects [24].
- Reference levels: These levels are indicated for purposes of practical exposure assessment to determine if it is likely that the basic restrictions being exceeded. Some reference levels are derived from relevant basic restrictions using measurement techniques and/or calculation, and others are related to perception and to adverse indirect effects of exposure to electromagnetic fields [24].

Biological effects of electromagnetic field on human body

According to physical laws, the energy is as high as electromagnetic wave frequency is great. The effects of electromagnetic waves on the human body are highly dependent on proper mechanisms of action at each level of energy (Table 2).

Biological effect of electromagnetic field on human body [28]

Tissue permeability to magnetic fields is the same as that of air. Consequently, the field within the tissues is identical to the external field. The humans and animals do not disturb this type of fields; their main interaction with the magnetic fields is expressed by Faraday's law. Electric fields can also be induced by movement in a static magnetic field. Regarding the exposure of humans to magnetic fields, the main assessment criteria applied are:

- The most intense electric fields are induced in the most corpulent body;
- The induced electric field and associated current depend on the orientation of the magnetic field relative to the exposed body. The induced fields in the body have a maximum intensity when the field is perpendicular to the body;
- The distribution of the induced electric field is a function of the conductivity of the various organs and tissues [29].

The energy deposition in tissues depends on two major factors; the wavelength determines the reached depth, and radiation intensity. Objects effectively absorb the wave when they have approximately the same size as the wavelength. Thus, the infrared will be completely absorbed in the first few millimeters of the skin inducing stimulation of skin and sensation heat [28].

Effects of electromagnetic waves on biological systems

Literature conducted on the effects of non-ionizing radiation is large and sometimes controversial. Epidemiological studies and the results of in vitro and in vivo experimental studies carried out in recent years have highlighted the biological effects of electromagnetic field. These effects caused DNA and cell damage such as strand breaks of DNA, changes in the chromatin conformation, formation of micronucleus in

Table 2: Biological effect of electromagnetic field on human body [28].

Radiation	Mecanism	Pathologic effects
X and gamma ray	Ionisation	Cancer
Ultraviolet	Chemical modifications	Skin cancer, skin aging, keratoconjunctivitis, Erythema.
Visible light	Photochemical réaction	Macular degeneration
Infrared	Surface heat	Cataract, retinal burn.
Microwaves and radiofrequencies	Deep heat	Temperature increase in Tissus
extremely low frequencies	Electric tension	Schock

different cell types, cell defects and apoptosis [30-32]. Other studies have found no effects observed following exposure to electromagnetic waves [33].

Various studies have shown that electromagnetic fields with low frequency and high frequency caused breaks in DNA strands. These results led the World Health Organization (WHO) in 2006 to give high priority to research into possible genetic modifications. Researchers have used the comet assay to observe any DNA damage induced by electromagnetic fields. Results showed that cells of human connective tissues exhibit a DNA strand breaks under the effect of low frequency electromagnetic fields alternately switched on and off at regular intervals [34].

Some results showed the existence of a relationship between exposure to electromagnetic fields and the increased incidence of the occurrence of some tumors types, particularly leukemia and brain cancer [35,36]. Several studies using different types of cancer cells showed contradictory effects on oxidative stress. Exposure of HL-60 cells to 100 mT for 13 min has no effect [37]. However, exposure for 2 hours to 6 mT increased oxidative stress in tumor cells U937 monocytic [38]. Reducing apoptosis may be a result of increased risk of carcinogenesis. Nuccitelli et al. [39], observed in tumor cells U937 monocytic a correlation between the reduction of apoptosis and modulation of membrane potential induced by exposure to 6 mT. These observations are supported by studies of Tenuzzo et al. [40], they exposed the cells to 6 mT up to 24 hours and noted a reduction of apoptosis and changes in the influx of free calcium. Abdelmelek et al. [10], reported that the static electromagnetic field (128T) increased the concentration of norepinephrine in skeletal muscle associated with sympathetic hyperactivity in rats. Chater et al. [9], showed that subacute exposure to static electromagnetic field stimulated the biosynthesis of plasma corticosterone and metallothionein in female rats and increased apoptosis. The mechanism of this stress effect induced by the electromagnetic field may be linked to oxidative stress [9]. There are many scientific data involving the electromagnetic field in the generation of free radicals such as superoxide anions in various cells (macrophages and monocytes) and organs (liver and kidney) [41-44]. Furthermore, several results showed that the magnetic field induced changes in enzyme activity, gene expression, changes in the structure and function of cell membrane and DNA damage [45-47]. In fact, previous studies showed that exposure to magnetic field increased DNA single-and double-strand breaks in rat brain [48]. A study on the treatment effect of zinc on oxidative stress induced by exposure to magnetic fields showed that the magnetic field (128 mT, 1 hour/day for 30 days) caused oxidative stress in the tissue et renal DNA. Indeed, it was able to of disturb the oxidant-antioxidant balance in different rat tissues. This imbalance was observed by a decrease in cytosolic GPx, CAT, and SOD activity in kidney and liver of rats. An increase in the level of MDA was also observed which could be explained by the lipid peroxidation [49].

Radiofrequencies

The spectrum of radio waves extends from 0.5 MHz in the AM radio band to about 30000 MHz in the radar band. Devices emitting radio frequencies have become ubiquitous in homes, offices and schools. Exposure to such a spectrum is quantified as radiofrequency energy flow per unit area (W/m^2) [50]. Figure 2 band of radio waves [51]. Radiofrequency waves are long. Cell phones mainly use two frequency bands; 900 MHz (λ=33 cm) and 1.9 GHz (λ=16 cm). Therefore energy is deposited on a longer journey. According to the frequencies used by the various wireless technologies, the depth of penetration will reach a few centimeters [28]. Table 3 Penetration depth of radiofrequency into human tissues [28].

Characterization of wireless waves

Wireless waves or WiFi is a LAN wireless technology that uses radio frequencies as the carrier signal in order to extend the Ethernet network to a zone geographically

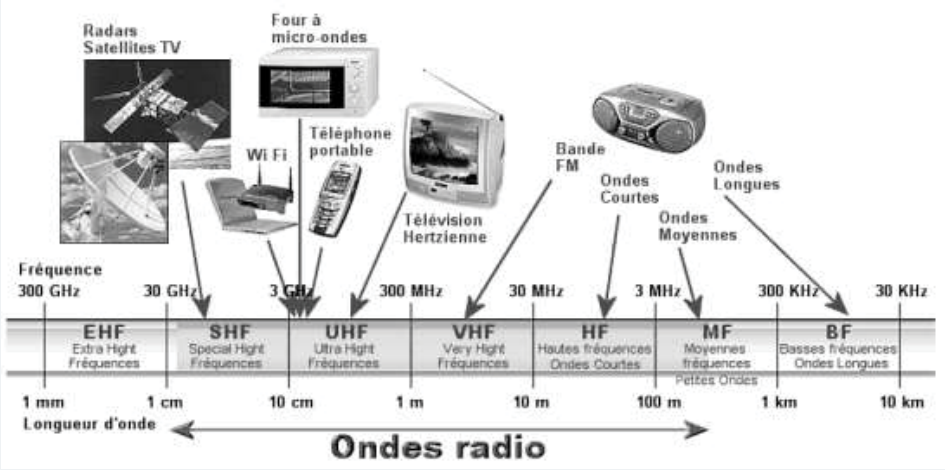

Figure 2: Band of radio waves [51].

Table 3: Penetration depth of radiofrequency into human tissues [28].

Wireless technologies	Frequency	Penetration deep
residential cordless phone systems	5 GHz	<1 cm
Headset "Bluetooth", Wifi	2.4 GHz	1 cm–2 cm
Cell phone	1.9 GHz	1 cm–3 cm
Cell phone	900 MHz	3 cm–5 cm
Radio waves (FM)	100 MHz	>30 cm
IRM	40 MHz, 100 MHz	>30 cm

distant. The connection between the different points is composed of an antenna for transmission and reception and a processing module for modulating and demodulating the signal [52].

Regarding the safety of emissions Wifi, two dangerous factors are advanced:

- Electromagnetic radiation inherent to the wireless technology;
- The value of used frequency which is around 2.4 GHz

In fact, the water resonance frequency which constitutes most of the human body is of 2.45 GHz. This frequency coincides with frequency spectrum used by WiFi which rising concerns among the general public [52].

The technical standard for transferring data by hertzian waves is IEEE 802.11 and its variants such as IEEE 802.11a, IEEE 802.11b. This standard is established by the organization of American standards IEEE-SA (Institute of Electrical and Electronics enginers-Standards Association). This standard describes the technical realization of the radio interface between the base station and mobile stations [53].

Signal propagation theory

The radio waves propagate in a straight line in several random directions which weaken with distance. When meeting an obstacle, part of its energy is absorbed and the other part continues to spread attenuated way. Radio waves can be reflected and diffracted when they encounter an angle [53].

Access points and bridges WiFi

An access point allows the interconnection of wireless equipment. Communication is limited to the signal coverage area that spreads 360° via Wifi antenna. We recommend a maximum of twenty clients per access point that must be placed in height to avoid environmental disturbances. The wireless bridge allows extending network to a remote geographical area. Indeed, the signal spreads several kilometers along the equipment.

Therefore, the access point allows the use of inside network while the access bridge allows the use of the network outside and in open field [53].

Health regulations

The European Directive 2004/40/EC sets the minimum safety and health requirements for limiting workers' exposure to electromagnetic fields. It is defined in terms of the values frequency of quantities relating to electric and / or magnetic beyond which preventive measures are to be implemented [29]. Table 4 Limiting public and workers' exposure to electromagnetic fields [29].

Biological effects of radiofrequency

Several studies showed that low-level RF energy could induce cancers such as leukemia, immunological disorders, deficiency in the blood-brain barrier, neurological anomalies such as headaches, disturbances in sleep and difficulty in concentration [54,55]. Exposure to low power RF can affect the cholinergic system. This sensibility could be due to a decrease of the intake of choline and activation of endogenous opioid neuroreceptors [56-58].

The causal chain that begins from RF exposure to death contains several steps. Each step may be the precursor to the next step. For interaction of radio frequencies with molecules, cellular structures or tissue, the transduction mechanism is the first crucial binding in the causal chain [50]. Figure 3 Radiofrequencies interaction with biological systems [50]. Radio frequencies and microwaves cause tissue heating. This thermal effect constitutes the standards basis of exposure for workers and the public. According to authors, the molecular damage caused by radio frequencies and microwaves activated the reaction of the cells. The natural defense mechanism was subsequently activated against this kind of stimulus. Such a reaction can be detected through the increase in reactive oxygen species or by the increase of stress proteins [59-61]. In addition, the conditions of exposure to mobile phones and DECT have caused real bioeffects in memory and brain of mice [62-65]. Figure 4 exposure and radiofrequencies effect at varied powers [66].

Installation and use of Wifi in administrations, libraries and academic institutions are challenged. Indeed, some scientific studies showed that the WiFi are pulsed waves

Table 4: Limiting public and workers' exposure to electromagnetic fields [29].

Standard	electric field strength		Magnetic field strength		Magnetic induction		Equivalent plane wave power density	
	E (V/m)		H (A/m)		B (μT)		S eq (W/m2)	
	Public	Workers	Public	Workers	Public	Workers	Public	Workers
Bluetooth	61	137	0.16	0.36	0.20	0.45	10	50
DECT	58	127	0.16	0.35	0.20	0.44	9.50	47.50
Wifi	61	137	0.16	0.36	0.20	0.45	10	50
WiMax	61	137	0.16	0.36	0.20	0.45	10	50

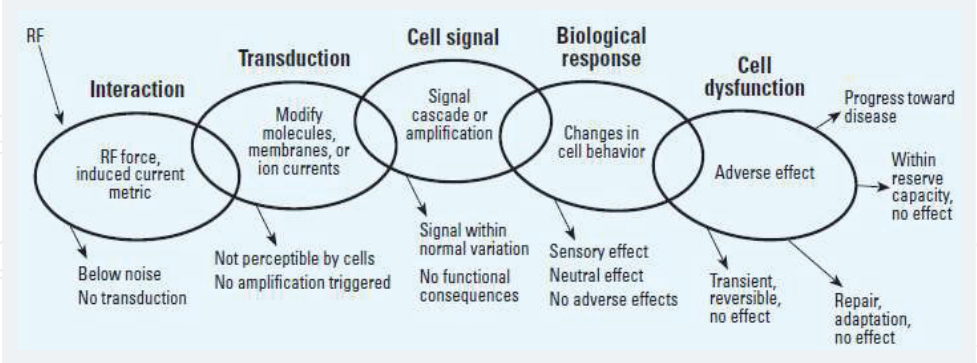

Figure 3: Radiofrequencies interaction with biological systems [50].

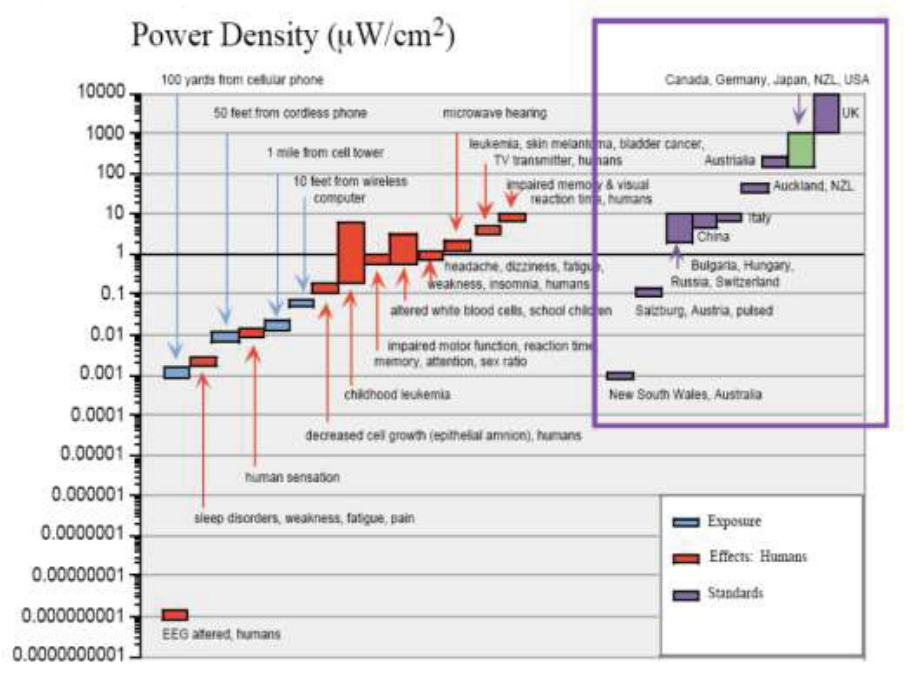

Figure 4: Exposure and radiofrequncies effect at varied powers [66].

using the same frequency as that used in microwave ovens. Therefore, the risks should be evaluated both on their thermal effects (proportional to the power density) and their non-thermal effects in the medium and long term [1]. The power absorbed by biological tissue per unit time could be transform to stored energy which induced increase in temperature (hyperthermia) localized or in full body [29].

Consequently, effects of radiofrequencies could be:

- Thermogenic effects: electromagnetic waves are absorbed by living tissue and it degrades into heat causing hyperthermia. In the case of Bluetooth technology, WLAN and DECT, low power implementations could not disrupt the thermoregulatory mechanisms human body [29].
- Non-thermogenic Effects: the electromagnetic waves could be causing some biological effects; cellular (cancer), endocrine, immunological, neurobiological effects and potentiating effects associated with other aggressive agents [17].

In addition, radio frequency interference with pacemakers is theoretically possible. This is an electromagnetic problem complicated by the biological environment (patient's body). At a distance less than 10 cm between a radio and a pacemaker minor disturbances have been recorded [67,68].

Conclusion

In this work, we tried to characterize the electromagnetic field and specifically the RF and their interactions with biological systems. Several scientific studies showed existence radiation effect on health. However, these studies are insufficient to confirm the effects directly related to the cause. Thus, more advanced epidemiological research must be done to enhance or reduce the uncertainties raised about the health impact of electromagnetic waves.

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