Quantum Biology and Healthcare: the Synergistic Bioeffect of Weak Electromagnetic Fields (EMFs) on Human Bodies

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Abstract

Human bodies are constantly exposed to environmental electromagnetic sources. Both electric and magnetic fields are known to have an active role in altering biological activities. In the present report, the focus will be exclusively on investigating the role of physiological exposure to magnetism. While strong magnetic fields (MFs) are known to induce potentially harmful thermal effects on living systems, there is no existing evidence suggesting possible negative side effects on biological systems from exposure to low-intensity magnetic fields. In recent years, the fast-growing field of quantum biology has focused on characterizing the complex interactions initiated by weak magnetic fields on human bodies through the laws of quantum physics. Even though there is still little understanding of the exact mechanisms, there is sufficient evidence demonstrating short- and long-term physiological changes elicited and, possibly controlled, by magnetic sources. This paper presents a summary of the mechanisms that are potentially, and possibly mutually, involved in eliciting biological reactions to magnetic exposure, supported by experimental evidence. The current understanding of human electromagnetic exposure suggests a potential future role of electromagnetic therapies as non-invasive, effective, and well-tolerated treatments for chronic and acute illnesses.

Keywords: quantum biology, magnetic fields, no side-effects, DNA and ATP synthesis.

1. Introduction

In the 17th century, Descartes' mechanistic approach to human physiology was conventionally used to characterize the body as a sum of separate compartments that do not cooperate with each other. Thanks to the advancement of new technologies over the past century, it is now established that the body is a highly hierarchic structure made of interconnected and interdependent systems that can be investigated from a macroscopic to a microscopic level, and vice versa. Nowadays, human anatomy and physiology are characterized as a single entity not only with the use of classical mechanics (i.e., Newton's laws of motion to model body movement) but also with the laws of quantum theory. In fact, the dynamics of biological processes and the energy exchanges among organs, cells, and organic molecules share quantum properties with smaller particles and do not exclusively follow the rules of classical dynamics [1], [2]. Among other important effects, the quantum nature of electrodynamics at the microbiological scale impacts molecular recognition, the way proteins function, and DNA synthesis rate [3]. Thus far, the growing understanding of quantum physics is used to bridge the knowledge gap between the macroscopic and microscopic realms of biological processes, giving rise to a field better known as *quantum biology* [4].

All charged particles interact with external electromagnetic fields (EMFs) which influence their motions; for example, the Earth's magnetic field is weak and yet has an active role in development,

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metabolism, and information processing along with orientation and rhythmicity features in some animals [5]. In clinical applications, EMFs in the radiofrequency spectrum have been used for ablation procedures due to their thermal effects on living tissues and cancer cells [6]. Since the advancement of such technologies in everyday life, human bodies have been increasingly exposed to environmental EMFs from domestic appliances, power lines, and cellphones. As a consequence, the public debate has focused on the potential health hazards of EMFs, with teams of experts developing 'safety standard' protocols to reduce the level of exposure and preserve the general population's health [7], [8]. Thus far, there is insufficient evidence to support the claim that suggests a possible correlation between EMFs exposure and increased risk of cancer or neurophysiological implications [9].

In recent years, the interest of the scientific community has shifted onto characterizing the biomechanisms that result from the interaction of EMFs with the human body and onto understanding the potential use of EMFs as non-invasive, effective, and well-tolerated treatment [10]. In a dynamic environment such as the human body, the presence of electric and magnetic fields is mutually non-exclusive, leading to a complex interplay of the two fields upon diverse physiological structures. Before delving into the effects of superimposed electric and magnetic fields, it is first worth exploring the biological effects of one field or the other, independently. The purpose of the present paper is to review the current knowledge of the biological processes exclusively elicited by magnetic exposure, with a particular focus on the changes in gene expressions when in presence of a weak magnetic field.

2. Background

Strong magnetic fields (MFs) are known to induce substantial thermal effects with critical consequences on the human body. As a result, safety guidelines have been formulated limiting the average whole-body rate of exposure to high-intensity MFs [11]. On the other hand, low-intensity MFs from powerlines and mobile phones do not represent a potential hazard to life, as they have no thermal effects and safe biological effects on cells and tissues [12]. Clinical data and experimental results suggest the existence of non-thermal biological reactions to weak MF field exposure, with possible therapeutic use in neurological disorders, such as neuropathic pain [13]. Nonetheless, the exact mechanism of action of MFs on biological systems has yet to be found [14]. *Magnetobiology* is the discipline investigating the interaction of biological systems with external magnetic sources in the radiofrequency and extremely low-frequency spectra, where the strongest molecular responses have been observed [15]. In like manner, the electromagnetic field arising from biological tissues is a phenomenon better known as *biomagnetism* [16].

The regulation of cellular functionality in living systems requires the use of some sort of energy, either thermal or electromagnetic. The interactions resulting from exposing cells to a low-intensity energy source must be understood through the laws of quantum physics rather than classical mechanics [3]. The core principles of quantum theory can be applied to biological systems since atoms and molecules possess the dualistic wave-particle nature of quantum particles [17].

As previously mentioned, a strong magnetic field is a perturbation from the outside world causing severe thermal fluctuations, generally several order larger in magnitude than quantum energies [15]. In order to investigate small quantum biological effects (i.e., changes in concentration of different substances and signaling molecules), it is necessary to apply a low-intensity MF, capable of limiting the thermal disturbances that are commonly induced by strong magnets [20]. In support of the idea that low-intensity MFs have a non-negligible impact on human physiology, Baek et al. (2019) demonstrated that lack of exposure to the geomagnetic field has an impact on epigenetic signals and, thus, on cellular identity, even though its amplitude is on the order of few micro Teslas ($\sim 40\ \mu T$, hundred times smaller than the strength of a magnet in a refrigerator) [21]. In the following section, an overview, along with supporting clinical results, is provided of the most established quantum biomechanisms, describing the existence of biological processes responding to an external, low-intensity magnetic field.

3. Cyclotron resonance

A first description of ion cyclotron resonance was formulated in the early 1930s. Lawrence and Livingston (1932) demonstrated that charged particles, when exposed to and in resonance with an electromagnetic

source, interact with an accelerating force, causing the ion to follow a circular path, as shown in Figure 1, and, through this motion, to absorb and consequently release an amount of energy proportional to the intensity of the applied magnetic field [22], [23].

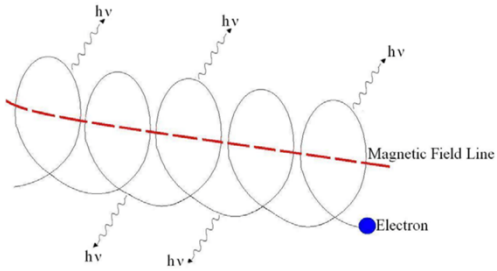

Figure 1. Electron cyclotron resonance. The charged particle senses an accelerating force and follows a circular path as consequence of the absorption and release of an amount of energy that is proportional to the intensity of the applied magnetic field *[24]*.

Likewise, cells, tissues, and whole organisms are influenced by magnetic sources through physical resonance processes [25]. However, an imperative attribute for a biological system to sense and react to ion cyclotron resonances is the existence of intracellular electric fields, which cause charged ions and molecules to oscillate at specific harmonic frequencies [10], [26]. In support of this hypothesis, evidence has been collected proving the existence of an electrical field controlling reactive oxygen species (ROS) in the mitochondria, suggesting the potential critical role of magnetism in regulating cell respiration [27], [28]. Thus, the wide variety of intrinsic oscillatory behaviors causes the human body to be susceptible to different magnetic frequency spectra.

There exist reproducible and consistent physiological effects emergent from magnetically induced mobility of cations (or anions) in an aqueous solution. In fact, observations have been made of the presence of cyclotron resonances among hydronium ions (H_3O^+), which are capable of carrying electric signals inside water structures, leading to information transfer within biological systems [29]. Also known as *proton hopping*, the delocalization of positive charges in liquid water, as shown in Figure 2, depends on temperature, pressure, on the strength of hydrogen bonds, and on the presence of a magnetic source resonating at the cyclotron frequency of H_3O^+ [26], [29], [30], [31].

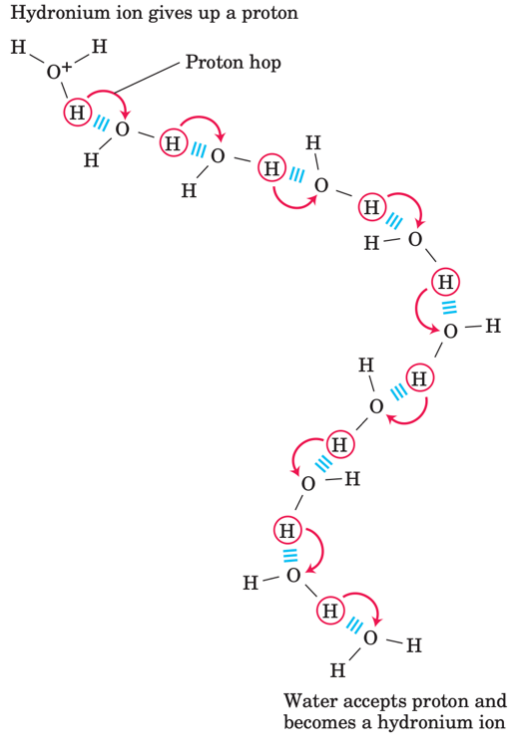

Figure 2. Proton hopping. Positive charges delocalization in liquid water is modulated by magnetic fields *[57]*.

Calcium ions, along with liquid water, are currently the most used targets for investigating the interaction of biological systems and magnetic fields, since these ions play a regulatory and messaging role in mammals. For example, the presence of a MF at the Ca^{2+} cyclotron frequency induces the upregulation of gene expressions. This includes chondrogenesis for cartilage repairs and neuronal differentiation, related to tumorigenicity reduction [32], [33]. These results demonstrate that cell proliferation and tissue reparations can be manipulated, suggesting a possible role of magnetic fields, tuned at the ion cyclotron resonance of specific ions, as regenerative treatment for bones, muscles, and nerves without any specific side effects [34]. Along with hydronium and calcium ions, biological reactions to magnetic fields at cyclotron resonances have been observed in the literature for ions such as magnesium, potassium, lithium, and zinc [35], [36].

Despite the amount of evidence, experts in the field have failed to prove the significance of the ion cyclotron resonance on living organisms due to the lack of a theoretical model that could exclude or confirm its dependency on thermal noise [20], [15].

4. Radical pair mechanism (RPM)

One of the most accepted hypotheses of magnetic field effects on biological systems is the radical pair mechanism. Its action is effective at a field intensity as low as the geomagnetic field [37]. Unlike the cyclotron resonance mechanism, which depends on specific frequencies, the effects of RPM are proportional to the intensity of the applied magnetic field [38]. Similarly, however, to cyclotron resonance, RPM takes effect at energy levels orders of magnitude smaller than thermal motion [39].

RPM is initiated when in presence of organic compounds, where paired electrons on the same orbital are orientated in an antiparallel fashion, according to the Pauli exclusion principle [40]. In so many words, the exclusion principle states that an orbital can have only two electrons at most, and one of them must be spin-up while the other is spin-down so that the particles can be differentiated. Following a bond breakage and in absence of an external magnetic field, radical-pair intermediates are created and electrons relocate to their respective molecules maintaining their initial orientation at a degenerate energy level, in what is known as *singlet spin state*. The presence of an external magnetic field, on the other hand, can cause one of the electrons to spin and to be aligned with the field while the other stays misaligned, leading to the *hyperfine splitting* of the energy levels. The 'torque' event flips the spin of one of the two electrons generating a *triplet spin state* (see Figure 3) [37]. This hyperfine splitting can change the chemical dynamics of a biological process both by changing the rate of reactions and by redistributing the formation of yields to completely new singlet or triplet products or to the recombination product [41].

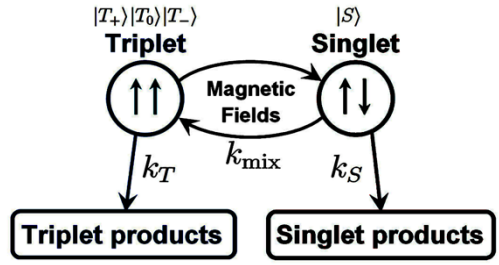

Figure 3. Reaction scheme for radical pair mechanism. The presence of an external magnetic field changes the rate of S-T mixing (k_{mix}) and the variety of product yields.

In addition to hyperfine interactions, the complexity of magnetic bioeffects through RPM is further explained by the Zeeman splitting which prevents the radical-pair intermediates from easily recombining into their original bond. In fact, MFs perturb the orbital interactions of the triplet spin states into two additional non-degenerate levels, separated by an energy gap that is proportional to the intensity of the applied magnetic field (see Figure 4) [42].

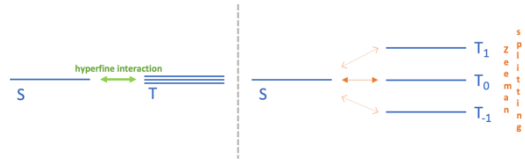

Figure 4. Zeeman splitting. Picture adapted from Kuno et al. (2015) *[42]*

Thus, an external magnetic field interacts with RPM through both spin and orbital magnetic moments altering the kinetics of biochemical and biomolecular reactions [43]. RPM is a well-established mechanism in birds, used as a tool for orientation during migration and proven by the presence of flavoprotein cryptochrome, a complex photoactive protein target of the magnetic field [45]. In humans, radicals are present as reaction intermediates or as free radicals, suggesting their possible susceptibility to weak external magnetic fields. However, specific targets of RPM have yet to be found [46].

Being able to control RPM with the application of an external magnetic field can influence the outcome

of biological processes, such as the rate of ATP and DNA synthesis [43], [47]. ATP yields are the product of ion-radical reactions mediated by the presence of a nuclear-magnetic isotope, an isotope whose nucleus has an unpaired number of protons and neutrons. An unpaired electron interacts with a magnetic nucleus through magnetic coupling triggering the S-T conversion and shifting the probability towards the triplet channel of ATP synthesis. Buchachenko and Kuznetsov (2008) demonstrated that coupling with magnetic nuclei initiates an RPM mechanism leading to a rate of ATP synthesis that is 2-3 higher compared to enzymes carrying non-magnetic nuclei [43]. In a similar fashion, DNA synthesis has an isotopic dependence on magnetic nuclei suggesting a possible use of electromagnetic therapies for biomedical purposes [47]. Evidence has shown an RPM control on the rate of DNA Polymerase Beta (DNApolB), a species found to be over-expressed in malignant tumors. RPM controls the spin conversion of two magnetic nuclei occupying DNApolB catalytic sites, leading to a significant decrease of DNApolB destabilizing yields, thus, preventing the proliferation and circulation of tumorigenic cells [48], [49].

Magnetic control of RPM modulates the rate of DNA and ATP synthesis in vivo, suggesting the possible use of electromagnetic exposure on biological systems for prevention, treatment, and recovery of genetic degenerative diseases. Due to the complexity of biological systems, the main challenge remains to find specific targets that are exclusively affected by RPM, and not other magnetic-sensitive mechanisms, and to select the ideal magnetic sources for beneficial, significant, and controlled effects [39], [50].

5. Ion interference mechanism (ions bound to protein inside a cavity)

Among most accepted models, there exists an ion interference mechanism which causes changes to the probability density for an ion to bind within the cavity of a protein (i.e. a pocket on the surface or interior of a protein with binding properties) and, thus, changes the protein interaction within the physicochemical surroundings [51]. Similar to the radical pair mechanism, such models do not depend on the transformation of magnetic field energy into ion-kinetic energy and, thus, do not generate thermal disturbances [52]. First evidence of the ion interference mechanism was addressed by Lednev (1991), who demonstrated a shift in the equilibrium of the Ca^{2+}-Calmodulin reaction leading to different biological yields; this model is consistent and illustrates the interplay between biological systems and weak magnetic fields in the most extensive fashion [15].

This mathematical model characterizes the behavior of an ion cloud inside a protein cavity (see Figure 5).

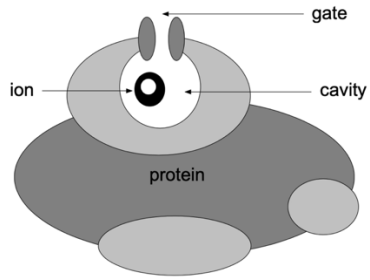

Figure 5. Ion cloud is bound into the cavity of a protein *[15]*. The behaviour of the ion cloud can be controlled by an external magnetic field, through both amplitude and frequency changes.

Under specific conditions dependent on the frequency and intensity of the magnetic sources, the cloud rotates inside the cavity and might be able to escape the gate due to an alignment of phase difference between the interfering angular modes of the ion wave function [25]. This movement of small molecules inside the cavities is a non-thermalized rotation since the cavity walls protect it from thermal vibrations [20]. Procession of ions can, in turn, result in a macroscopic rotation of the entire protein or aminoacidic chain [15]. Experimental evidence does not contradict the theoretical formulation for both the amplitude and frequency spectrum on calcium uptake in human lymphocytes and on fibroblast cell proliferation [25]. Furthermore, the model takes into account the possible use of pulsed electromagnetic fields without contradicting the experimental results, as shown in Smith et al. (1991) and Aarholt et al. (1982) [53], [54]. So far, the ion-interference hypothesis is a good representation of the interaction between biological systems and magnetic fields with some shortcomings; for example, the numerical solution is not exact yet, due to the dependency of the ion-bound state of the protein

cavity to conditions such as temperature, pressure, and relative density [15].

6. Discussion

In recent years, the biomechanisms that arise from the interaction of living systems with an external electromagnetic source have been identified with the use of classical mechanics and quantum theories. Still, the biological gap between quantum states and the body as a whole has raised skepticism about the beneficial potentials of magnetism in human health. Since 1979, the entire scientific debate has focused on finding possible negative effects that magnetism exposure could have, including possibly leading to tumorigenic side effects. The use of high-intensity sources must be regulated through 'safety standard' protocols. These measures are imperative, since strong electromagnetic fields induce potentially harmful thermal effects on human bodies. Just as X-rays are regulated, so too must their strong, purely magnetic analogies, be controlled. On the other hand, any correlation between low-intensity EMFs exposure and either tumorigenesis or thermal effects has been, thus far, discarded. The absence of negative side effects has created the foundation for possible use of low-intensity electromagnetic therapies as non-invasive, effective, and well-tolerated treatment. Magnetic quantum interactions with matter particles (i.e., electrons, protons, cations, anions, atomic nuclei, *etc*.) clarify the potential role of magnetic exposure to biological systems. However, the interplay between magnetic fields and biological processes is elaborate due to the complexity of human anatomy and due to the existence of hierarchical structures that cause extreme entanglements inside the physiological network.

The previously mentioned mechanisms are all dependent on the presence of water, charged particles, or magnetic-sensitive molecules inside the organism. All these mechanisms are valid, proven by clinical evidence, and, most certainly, they mutually contribute to the overall response of a living system. Most importantly, biological processes show a clear dependency on the surrounding magnetic fields, such as their amplitude and frequency. For example, the cyclotron resonance mechanism takes advantage of the intrinsic oscillatory behavior of charged particles and of their ability to synchronize with an alternating magnetic field through a frequency dependency. On the other hand, the radical pair mechanism, using both hyperfine interactions and Zeeman splitting, exhibits a behavior that is dependent on the amplitude of the applied magnetic source. The latter, and currently most accepted, ion-interference model has a strong theoretical background and a mathematical formulation that depends on the amplitude, the frequency of the magnetic field, as well as on the shape and repetition of its pulse train.

Nowadays, the laws of quantum biology confirm the existence of interactions between biological systems and magnetic exposure at low intensities and at a wide frequency range. Evidence of non-thermal, highly reproducible effects rule out the existence of one single type of specialized biomolecules responsible for magnetoreception, but rather different biomolecules with different characteristics are possible candidates to become EMF targets. Having a large magnetic moment is a general requirement for these biomolecules, such that a slight change in magnetic energy, much smaller than thermal fluctuations, can elicit a significant biological response.

Additional investigations must be conducted to further validate the significance of the present results; moreover, additional experimental data should be collected to identify specific targets to EMFs therapeutic. So far, an amplitude and frequency dependency of biological processes to magnetic exposure has been confirmed, proven, and some attempts have been made to fully characterize it. Future advancements can lead to the potential use of electromagnetic targeted therapeutics to control the outcomes of specific biological processes and help the recovery to chronic and acute illnesses that are, thus far, considered incurable.

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