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Biological Effects Due to Hypomagnetic Field and Its Research Progress

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Abstract

The biological effects due to hypomagnetic field (HMF) is a very important subject for aerospace travelling and space station living, and a large number of studies on the bioeffects of the HMF have been carried out; however, many essential problems, such as physical mechanism, the harmful for human beings and other living organism of the biological effects, are still remaining unknown. In order to promote the solution to these problems, we assembled, classified and analyzed the studies on the biological effects due to the HMF. About one of the essential problem, i.e. the physical mechanism of the biological effects of HMF, we think that the yield Φ of the singlet spin state of the radical pair theory, that is $\Phi^0_{s(\theta)} \approx \frac{1}{2} - \frac{1}{4}\sin^2\theta - \frac{\gamma B_0^2}{A_z^2}(\frac{3}{4}\sin^2\theta - \sin^4\theta)$ ' is the probable solution, since even the external magnetic field B_0 is very weak, the $\Phi^0_{s(\theta)}$ is still a monotonous function of θ. About the important research contents in the future, we chose several research hot points by comparing the large quantity of studies.

Keywords: Hypomagnetic field (HMF), Biological effect, Quantum mechanism, Cellular and molecular level, Singlet state yield.

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Contents

1. Introduction

Biological effects due to hypomagnetic field (HMF) regarded as a very important subject originated from the universe exploration, such as aerospace travelling and space station living plan. The Biological effects due to HMF is also often call as bio-HMF response. It is based on the research of static magnetic fields (SMFs). The interaction of SMFs with living organisms has early been become an important subfield [1] many studies on biological effects of SMFs have been carried out [2-4] and the first basic research is that the SMFs are classified as following four grades. (1) the weak grade (<1mT); (2) the moderate grade (1mT -1T); (3) the strong grade (1T-5T); and (4) the ultrastrong grade (>5T) [1]. With the research developing of the interaction of SMFs with living organisms, and of the aerospace travelling and space station living plan, the interaction of very weak magnetic field with living organisms has also been become a very important subdiscipline. When the SMF is extremely weak (<5uT), it has a special name, is called a hypomagnetic field (HMF [5]. About the beginning of research on the bio-HMF response, it began to attract attention of the field of space life sciences is at the last years of 1960s, the scientists of USSR made an important contribution to the early research of bio-HMF response [5] and this research filed has been highly regarded in the world since 1980s [5-7]. The presentation order of the contents of this paper is as follows. The representative studies in bio-HMF response are introduced in part 2; studies at several levels for searching the mechanisms underlying the bio-HMF response are introduced in part 3; part 4 is the important hot research points in the future; part 5 is the applications of the researches on the bio-HMF response; and the main contents are summarized in part 6.

2. Representative Bioeffects Caused by the HMF

During the evolution process, all living organism experienced the action of the Earth's magnetic field (geomagnetic field, GMF), which is a natural component of their environment [8]. While, Interplanetary space is a natural HMF [5]. Because of the difference on intensity between GMF (35~70uT) and HMF(<5uT) [5] many effects appear when animals, plants and microorganisms are in the HMF [5]; [7-18] . Among these effects, the special important one is the effect caused by the HMF on locomotion of mammalians. Indeed the HMF is one of the key environment risk factors for astronauts traveling in outer space [19] which has previously been shown to repress locomotion of mammalians [16]. As the locomotion of mammalians is related to not only the motor system, but also nervous system and endocrine system, therefore, in order to find out the origin of repression of locomotion of such systems, it is necessary that the systems must be in a HMF environment [16]. From above, one can see the reason of repression of locomotion is very complicated, because any change of each one system may bring the repression. What is the mechanism underlying so many effects of living organisms in the HMF?

3. Studies on the Mechanisms Underlying the Bioeffects of HMF

In order to understand the origin underlying the biological effects, many attempts have been carried out at the cellular level, the molecular level, the further deep quantum mechanics level, and with the synthesis method, the details are as follows.

3.1. Studies at Cellular Level for Investigating the Mechanism of the Bio-HMF

At the cellular level, some researches have been reported. The decline of cell viability and mitochondrial activity in mouse skeletal muscle cell in a hypomagnetic field was found [20].The environment of hypomagnetic field can cause changes in blood leukocytes and plates in mice, which may affect the immune system and characteristics of blood coagulation [21].The concentration of neutrophil granulocyte was significantly increased after one-month HMF exposure [22].The continuous HMF exposures can accelerate the proliferation of human neuroblastoma cells by promoting G1-phase progression [23]. A hypomagnetic field can aggravate bone loss induced by hindlimb unloading in rat femurs [24]. A hypomagnetic field of 500nT retarded osteoblast differentiation was showed [25]. A hypomagnetic field can alter action assembly and inhibit cell motility in human neuroblastoma cells [26].

3.2. Studies at the Molecular Level

In order to investigate the mechanisms underlying the bio-HMF response, at the molecular level, there is also a number of studies have been carried out. The HMF exposure significantly affected the transcription of gens related to macromolecule transport, metabolic process and mRNA processing, and to the subsequent pathways involved in the organization of the cytoskeleton, regulation of chromatin condensation, transcription, and brain function [27]. Transcript levels of gens that may affect cryptochrome-related hypocotyl growth and flowering in Arabidopsis by a HMF were examined [12]. Several theories have been advanced to describe the effects of hypomagnetic fields [5] [28, 29]. Among these theories, the radical-pair reaction theory is a leading candidate mechanism to this day. Based on the radical-pair reaction theory, cryptochrome gens (CRYs) have been proposed to be the putative magnetoreceptor genes, which enable an organism to detect magnetic fields [12]; [30, 31]. At the cellular and molecular level, in vitro and in vivo studies have shown that cell cycle progression, tubulin assembly, DNA super condensation and H_2O_2 production are potential targets of the HMF [22]; [31-36].

3.3. Studies on Change of the Electrical Properties of Biological Tissues Induced By the HMF

In order to explore the biological effect due to the HMF, many studies on change of the electrical properties of biological tissues induced by the HMF have been carried out. Because the dielectric properties and conductive properties of biological tissues are very important for diagnosing the physiological conditions and for understanding the basic biological processes [37-40] except the studies on these aspects with simulated microgravity method[37, 38] these properties of biological tissues (for rat gastrocnemius, whole blood) induced by the HMF have also been carried out [37, 38] and the following important results are found. (1) The conductivity of gastrocnemius increased after four weeks HMF exposure; (2) the image part of the complex conductivity ε″, and the image part of the conductivity κ″are both decreased. (3) Marked increase in permittivity up

to 19.6% and conductivity up to 19.1% were obtained for rat whole blood. (4) The characteristic frequency at which the permittivity and conductivity are increased obviously is 0.1MHz.

3.4. Studies on Physical Mechanism of the Bio-HMF Response

Although a large quantity of studies at cellular and molecular level has been carried out, the basic theoretical mechanism is still unknown. How to find the deepest level mechanism underlying the bio-HMF response? Many researchers proceeded the study from investigating the avian navigation [41-47] the most concerned method is the quantum mechanics theory. Its basic thinking is that the physical changes are the base of all changes in living organisms, therefore, in order to exhaust the mechanism of the bio-HMF, it is necessary to study the state change of atomic or electronic particles of the living organism caused by the HMF; One of the frontier theories is the radical-pair (RP) model [48-57] and its basic process is as follows. (1) Propose that a photon excites an electron, and makes the electron transfers from a donor to an acceptor; thus a RP singlet spin state S can be generated. (2) In the total angular-momentum representation, the vertical component A_z of the anisotropic hyperfine coupling tensor induces the interconversion between the singlet spin state S and the triplet spin stateT_0; the horizontal component A_x and A_y induce the transition between the singlet spin state S and the triplet spin state T_+ and T_-. (3) The A_x and A_y can induce the transition between triplet spin state T_0 and triplet spin state T_+ and T_-. (4) The effect of external magnetic field B is its horizontal component B_x also can induce the transition between triplet spin state T_0 and triplet spin state T_+ and T_-. Thus the external field B affected the yield of singlet state S, therefore the external B can be detected [58, 59]. The relation between yield Φ of the singlet state S and the external field B_0 and its orientation angle θ is given as follow [58]

$$\Phi^0_{s(\theta)} \approx \frac{1}{2} - \frac{1}{4}\sin^2\theta - \frac{\gamma B_0^2}{A_z^2}\left(\frac{3}{4}\sin^2\theta - \sin^4\theta\right) \quad ①.$$

Where $\Phi^0_{s(\theta)}$ is the singlet yield; A_z is the vertical hyperfine coupling component; $\gamma = \frac{1}{2}\mu_B g_s$ is the gyromagnetic ratio, with μ_B the Bohr magneton and g_s the g factor of the electron, here g_s=2; B_0 is the intensity of the Earth's magnetic field (namely the external field), and θ describes the orientation angle of the B_0 [59]. The last term is the second-order perturbation and $1/2-\sin^2\theta/4$ in Eq. ① plays a significant role in the singlet yield $\Phi^0_{s(\theta)}$ [58]. Notably, even when the local field is very weak, i.e., the value of B_0 is very small, Eq. ① is still a monotonous function of θ [59]. When B_0 is smaller than 5uT, is Eq. ① still true? It may be one quantum mechanism of the bio-HMF response, however there is no affirmative answer at present; it need a lot of experimental and theoretical studies.

Binhi VN proposed one different physical mechanism based on classical precessional dynamics of a magnetic moment in a thermally disturbed environment and includes a minimum of necessary parameters—the gyromagnetic ratio, thermal relaxation time, and rate of downstream events generated by changes in the state of the magnetic moment [39, 40].

4. Research Top Points on the Bio-Effects of HMF

Although many researches on biological effects due to HMF have been done as described above, to solve thoroughly the mechanism underlying biological effects due to the HMF, it is necessary to investigate in many aspects. By comparing the large quantity of completed research works, we think that the following questions maybe the research top points.

4.1. What is the Clear and Precise Reason and what is the Whole Course of Repression of Locomotion of Mammalians?

It was proposed earlier that mitochondria are the organelle most sensitive to changes in environmental magnetic field [8]; [20]. HMF exposure reduces viability, energy production and mitochondrial activity of primary mouse skeletal muscle cells [20]. Mitochondrion can respond to HMF directly, and thus HMF-induced decline in cell functionally may result from reduction in energy production and mitochondrial activity [20]. Negative effects of HMF on skeletal muscle cells probably contribute to HMF-induced repression on locomotion in mammalians [20]. Can the experimental result on mitochondrion appear in other cells? A HMF can influence the different cells in different systems [20-26]. Which system is the first one affected by the HMF if the different systems' response to HMF is not simultaneous when a living organism is in a HMF? And do the systems have interaction when mammalians are in a HMF? Cryptochromes gens (CRYs) have been proposed to be the putative magnetoreceptor genes, which enable an organism to detect magnetic fields [12]; [30, 31]. The results of the research suggest the involvement of the cryptochromes in mediating the HMF effects [19]. But how do the cryptochromes involve in the course? Can the experimental results in human neuroblastoma cells in the hypomagnetic field [19] appear in other cells? Detailed structural and biochemical analysis of CRY proteins would elucidate how they may respond to changes in the magnetic environment [19] and that the further researches are needed to elucidate the reason and the course of repression of locomotion of mammalians.

4.2. Is the Bio-HMF Response a General Law in Living Organisms?

Although many effects appear when animals, plants and microorganisms are in a HMF, the answer is not sure because of limited researches. From the evolutionary theory, the answer may be sure, because all living organisms on the Earth have been exposed to the geomagnetic field (GMF), a natural component of the habitability environment, through the evolutionary history. In evolution, all living organisms have built their mechanisms to adapt the environment. When the environment changes, that is to say, when intensity of the magnetic field from that of the GMF to the HMF, living organisms may be surely have response accordingly.

4.3. What's The Relationship between the Quantum Mechanism and the Mechanism of Electromagnetics on the Bio-HMF Response?

The rat whole blood's electromagnetic parameters were affected by the HMF [37, 38].If Eq ① is one quantum mechanism of the bio-HMF response, what's the relationship between the quantum mechanism and the mechanism of electromagnetics? That's to say, can a function of electromagnetic parameters related a HMF and based on Eq ①be derived?

4.4. Can the Pure Bio-HMF Response be Gotten?

Bio-HMF response may be related with ambient alternating magnetic fields [5, 60] since in the experiments on a HMF, the alternating ambient magnetic fields is always present because of the magnetic and/or electric properties of the measuring instrument [20, 26]. The results on the experiments may be the comprehensive effects with a HMF and an alternating magnetic field. Therefore, the effects of ambient magnetic field HMF should be discriminated by using advanced experimental design in future experiments.

Beside those, there are some other questions, such as: although there are bio-HMF responses in molecular level [12, 27] can the biological effects be inherited? The cell with mitochondria can have bio-HMF response [20] and the cell without mitochondria just like red blood cell(RBC)can have no bio-HMF response [21] so what are the mechanisms of the results in cellular level? And are the mechanisms are general? If the mechanisms are general in bio-HMF responses, are they still true in biological effects due to magnetic fields except for HMF? The HMF can alter development of xenopus embryos [17] and it suggests the HMF can affect the cell communication, what are the mechanisms in molecular level underlying the two results and have the mechanisms intrinsic relationship with bio-HMF response in the cell with mitochondria [20] ? Therefore, there will much work to be done to elucidate the bio-HMF response. To do those works in the future is very valuable.

5. Applications of the Researches on the Bio-HMF Response

Since many effects appear when animals, plants and microorganisms are in the HMF [5]; [7-18] therefore, it is needless to say that the researches on the bioeffects of HMF will have many important applications, and the followings are considered as important possible applications at the present.

(1) HMF is one of the key environment risk factors for astronauts traveling in outer space, and the outer space living [19] (2) the further investigation of HMF effects would benefit the development of the health care strategy for the astronauts in the space mission [18] (3) to elucidate bio-HMF response may help to solve the mechanism for organisms to sense GMF [26] (4) stem cell culturing in the HMF, such a physical approach which stimulate the growth of neural progenitor/stem cells non-invasively, has great potency for clinical application in stem cell therapy [61] (5) the research on bioeffects of HMF is also important to protect the workers in the HMF on the Earth [5, 62]. With the development on the research of bio-HMF response, more and more uses will be found.

6. Summary

The micro mechanism underlying the biological effects due to the HMF is the key problem of the biomagnetics, and there has been no answer. By analyzing the radical pair magnetoreception model, We think that the yield Φ of the singlet state, $\Phi^0_{s(\theta)} \approx \frac{1}{2} - \frac{1}{4}\sin^2\theta - \frac{\gamma B_0^2}{A_z^2}(\frac{3}{4}\sin^2\theta - \sin^4\theta)$ is the probable solution, since even the external magnetic field B_0 is very weak, the $\Phi^0_{s(\theta)}$ is still a monotonous function of θ. About the important research contents in the future, we chose several research hot points by comparing the large quantity of studies. The representative Bioeffects caused by the HMF; studies at the cellular level, the molecular level, and with the synthesis method are introduced; and the applications of the researches on the bioeffects of HMF are also introduced.

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