Role of Electromagnetic Activity in Cellular Mechanics

Hanlin Liu

Beijing Huijia Private School, Beijing, 102200, China

25liuhanlin@huijia.edu.cn

Abstract. The cell is the building block of life since it is the fundamental unit of all living things. Organelles, the cytoplasm, the nucleus, and other structures all have specific roles in cells. Genetic makeup, which controls cell growth, reproduction, and environmental response, determines the structure and function of cells. It is commonly known that cells communicate chemically and electrically. Cellular interactions via other physical fields are exactly the opposite. The electromagnetic field (EMF) is the most likely option for a different type of cellular interaction. This review delves into the role of electromagnetic fields in cells and their consequential impact on cell behavior. This gives a broad perspective on the basic construction and operation of cells, presents the notion of cellular mechanics, and deepens the understanding of the pivotal function of microtubules and centrosomes in cellular division. It also explores their interplay with the electromagnetic field. The discussion extends to how EMF influences ion channels on the cell membrane, a critical component in cellular communication, and the electrical properties of neurons. This review concludes by identifying the current limitations and gaps in EMF research in cells, such as constraints in experimental methods and technology, and the need for more comprehensive theories and models to fully understand these complex processes.

Keywords: Cell division, electromagnetic effects, cellular mechanics.

1. Introduction

The basic unit of life is the cell, which constitutes all living things, and therefore they are the bedrock of life. Cells contain various structures, including the nucleus, cytoplasm, and organelles, each with its unique function. The structure and function of cells are controlled by their genetic material, which guides cell growth, reproduction, and response to the environment.

Cell mechanics is a field specifically dedicated to studying the physical properties and mechanical behavior of cells. This field includes the forces that cells themselves exert on their surrounding environment. In recent years, due to the widespread use of electronic products, such as the increase in telemedicine visits from 840,000 in 2019 to 52.7 million in 2020 during the pandemic according to the American Medical Association data [1]. As electronic devices become increasingly prevalent, there is a growing focus on the impact of electromagnetic fields on cells, and research efforts in this area are progressively expanding. Therefore in recent years more and more essays have been written about the discovery that changes inside the cell are related to electromagnetic fields outside the cell [2,3]. Meanwhile, a number of studies based on various impacts of electromagnetic fields on cells have been reported, including cellular stress responses, inhibition of tumor cells, calcium-mediated cell fate decisions, abnormalities in fetuses and children, immune system functions, oxidative stress responses, and effects on adult stem cells.

2. Cell division

Cell division, specifically the process of mitosis, is an intricate and tightly controlled biological event. It involves a single parent cell dividing into two identical progeny cells, each containing an equal number of chromosomes as the original or 'mother' cell. This mechanism is of paramount importance for an organism's growth, repair, and general maintenance, playing a significant role in its overall health and longevity. Two key cellular structures, microtubules and centrioles, are at the heart of this process. During the interphase stage of the cell cycle, a period when the cell is not actively dividing, the centrosome undergoes duplication. The centrosome, an organelle that serves as the primary microtubule organizing center in animal cells, houses a pair of centrioles. This duplication is a preparatory step, setting the stage for the impending cell division. As the cell transitions from interphase to prophase, the initial stage of mitosis, the duplicate centrosomes relocate to opposite ends of the cell. Microtubules, integral components of the cell's cytoskeleton that serve various essential functions during cell division, begin to extend from these centrosomes. This extension forms a structure known as the mitotic spindle, a crucial player in the process of cell division.

During metaphase, the chromosomes, which have already duplicated and condensed, align along the cell's equator. Each chromosome is connected to both poles of the spindle via microtubules. This connection ensures that when the cell divides, the chromosomes will be evenly distributed to the two daughter cells. In anaphase, the microtubules contract, pulling the paired chromosomes apart and moving them towards opposite ends of the cell. This movement is followed by telophase, the concluding stage of mitosis, where the chromosomes reach the spindle poles and start to decondense.

Throughout this stage, the spindle apparatus disassembles, and a nuclear envelope reforms around the chromosomes at each end of the cell. Cytokinesis, the process of physically separating the cytoplasm, then follows, resulting in the formation of two distinct cells. In the end, each of these newly formed cells is equipped with its own complete set of chromosomes, identical to the mother cell, and its own centrosome containing a pair of centrioles. This intricate, finely-tuned process of cell division ensures the accurate copying and distribution of genetic information during the creation of new cells, thereby supporting the continuity of life.

This process of cell division is not only a marvel of biological engineering but also a testament to the complexity of life. It underscores the importance of each component, each step, and each process in the grand scheme of life. From the duplication of the centrosome to the contraction of the microtubules, each stage is critical to ensuring the successful division of the cell and the propagation of life.

3. Electromagnetic effects in cellular mechanics

The electromagnetic fields can influence the fate of cells, they can similarly affect the mechanisms within cells. Recently, more evidence shows that electromagnetic interactions greatly impact how cells behave and form [3,4]. This interaction impacts not only fundamental processes such as cell growth, differentiation, and migration, but also has profound effects on the development and health status of the entire organism [3-8].

For example, electromagnetic fields (EMFs) can have significant effects on the growth of organisms at different stages. During initial development, research indicates that EMFs can interfere with cellular division and differentiation processes, which are crucial for the establishment of body tissues and organs [4]. Such interference could potentially result in developmental anomalies if the exposure coincides with a critical developmental window [6,9].

In adults, EMFs can affect various physiological processes. For example, they can influence the function of the nervous system, potentially leading to neurological disorders. Studies have shown that exposure to certain types of EMFs can lead to symptoms such as headaches, anxiety, and depression [2,10,11].

3.1. Impact on mircotubule

Microtubules are part of the cell's cytoskeleton, formed by dynamically aggregated α- and β-tubulin subunits, creating a hollow tubular structure [9]. Microtubules play multiple important roles within a cell, such as participating in establishing and maintaining cell polarity, which is essential for directed cell movement and specific physiological functions. Moreover, during cell division, microtubules form spindles that help separate chromosomes into two new cells. Importantly, studies have found that since microtubules are tubular structures formed by protein aggregates, they can generate an electromagnetic field through longitudinal vibrations. Recent scientific investigations have uncovered that when organisms are exposed to nuclear electromagnetic pulses, it primarily influences the biological processes that are closely tied to the structure of microtubules. This includes a wide range of activities such as the assembly of spindle structures, the formation of bundles of microtubules, the organization of the microtubule cytoskeleton - a dynamic network of interlinking microtubules within the cell, and various other processes that are dependent on the proper functioning and structure of microtubules. These findings highlight the significant role of microtubules in cellular responses to nuclear electromagnetic pulse exposure [10]. However, there is currently no solid evidence to explain the specific mechanisms and functions of microtubule-generated electromagnetic fields. Centrosomes and microtubules have a close relationship [12].

3.2. Impact on centrosome

An article titled "Electromagnetic Interactions in Cell Behavior and Morphogenesis" published in the Front Cell Dev Biol journal in 2022 discussed how the electromagnetic field within cells governs the fundamental physical procedures of cellular biology [13]. The latest research results in the article show that the function of centrosomes in cells is not only as a microtubule organizing center. More importantly, centrosomes also serve as nano-electron generators in cells [13,14]. The spinal twists of centrioles convert the chemical energy of the cell into its electromagnetic energy. The model described in "Centrosome as a micro-electronic generator in live cell" by Johan Nygren and colleagues, which was published in Biosystems in 2020, gains significant endorsement from a plethora of experimental proofs. This model provides a refined explanation for the self-organized orthogonal setup of the two centrioles within a centrosome, achieved via the dynamic electromagnetic interplay between both centrioles of the centrosome [15]. This new function reveals the important role of centrosomes in generating electromagnetic fields and regulating cell behavior, providing a new perspective for us to understand the impact of the electromagnetic field on life processes within organisms [16]. In addition, this function of a nano-electron generator may provide new strategies for disease treatment. For example, in certain diseases (such as cancer), the function and structure of the centrosome often undergo abnormal changes, which may change the electromagnetic environment within cells and thereby affect cell behavior. If we can understand more deeply the mechanism of the centrosome as a nano-electron generator, and find ways to regulate its electromagnetic generation ability, it may pave the way for new treatments for these diseases.

3.3. Impact on calcium channel

The impact of electromagnetic fields (EMF) on cells is a complex process involving multiple biological mechanisms. Among the various mechanisms, a crucial one is that the electromagnetic field (EMF) can influence the ion channels present on the cell membrane. Ion channels are crucial in modulating the operations within cells. They manage the flux of ions, thereby significantly modifying the internal ionic concentration of cells, which subsequently impacts cell signaling and overall functionality [17]. These channels participate in a broad spectrum of cellular activities, such as the propagation of electrical signals in neurons, muscle contractions, and the regulation of heart rhythms. By facilitating the passage of specific ions across the cell membrane, they help to maintain the delicate equilibrium of ions inside and outside the cell, a state known as the membrane potential. This equilibrium is vital for the cell's proper functioning [17]. Moreover, ion channels are implicated in cell signaling processes. When a signaling molecule, like a hormone or neurotransmitter, binds to a receptor on the cell surface, it can instigate the opening or closing of particular ion channels. This alteration in ion flow can then set off a series of events within the cell, ultimately leading to a response. For instance, the influx of calcium ions into a muscle cell can instigate muscle contraction. Additionally, ion channels influence cellular functionality by affecting various cellular processes. For example, the efflux of potassium ions from the cell can aid in regulating cell volume. Similarly, the influx of calcium ions can activate enzymes, stimulate the release of neurotransmitters, or trigger other cellular responses [17,18]. For example, calcium ions are a key component of many cell signaling pathways. They partake in numerous biological activities, including the proliferation of cells, their differentiation, and programmed cell death [17,18].

Current research indicates that electromagnetic fields (EMF) can change the concentration of calcium ions in cells by affecting the calcium ion channels on the cell membrane. EMF can activate these calcium channels, causing oscillations in the calcium ions inside bone marrow stem cells [19]. These calcium oscillations can activate intracellular signaling pathways, which in turn affect the fate of stem cells, including bone formation, cartilage formation, and cell apoptosis [19].

Nonetheless, numerous factors may impact this process, including the frequency and strength of the electromagnetic field, the duration of exposure, and alterations in the cell type and condition.

3.4. Impact on the electrical properties of neurons

Latest studies also reveal the immediate impact of various electromagnetic fields on the electrical characteristics of neurons. Given that neuron activity is primarily dependent on the activation and deactivation of ion channels, which dictates fluctuations in neuronal potential and signal conveyance, electromagnetic fields have the capacity to modify the performance of these channels. Some investigations have discovered that electromagnetic fields can shift the activity of calcium ion channels, thus affecting the transmission of neuronal signals. However, this effect is considerably reliant on the specifics of the electromagnetic field, such as the frequency of the field and duration of exposure.

For example, in these studies, extremely low-frequency electromagnetic fields (ELF-EMFs) have been found to have significant multifaceted impacts on the nervous system. One important discovery is that ELF-EMFs can enhance neurogenesis in neuronal stem cells (NSCs).

ELF-EMFs can promote neurogenesis in neuronal stem cells by affecting their signal transmission and gene expression. For instance, ELF-EMFs can increase the expression of cell cycle proteins and neuron-specific proteins in NSCs, promoting the proliferation and differentiation of these cells. Moreover, ELF-EMFs can alter the morphology and migration of NSCs by affecting their cytoskeleton and cell adhesion, further promoting neurogenesis.

Additionally, research has found that ELF-EMFs can enhance neurogenesis in the hippocampal region of mice [19]. The hippocampus is an essential part of the brain responsible for learning and memory, where neurogenesis plays a significant role. ELF-EMFs can promote neurogenesis in the hippocampal region by affecting the signal transmission and gene expression of the neuronal stem cells there, which could potentially influence learning and memory functions [11,20].

4. Summary

Research on the electromagnetic field (EMF) in cells has made significant progress over the past few years, yet there are still noticeable limitations and shortcomings. These include constraints in experimental methods and technology. Despite significant strides in understanding the effects of EMFs on cell behavior, the technological tools available still have their limitations. Finer, higher-resolution tools are needed to measure and manipulate the electromagnetic fields in cells. Moreover, experimental conditions, such as the intensity and frequency of the EMF, could significantly impact the results, necessitating more precise control over these conditions. Furthermore, there is a lack of comprehensive theory and models: the understanding of how EMFs are generated in cells, and how they interact with biomolecules and biological processes, remains limited. More accurate theoretical models need to be developed to better understand these processes. As for the application in disease treatment: while some research has begun to explore the potential of EMFs in disease treatment, such as in tumor therapy, this work is still in its infancy. More clinical trials need to be conducted to determine the effectiveness and safety of these methods.

Therefore, more basic research is needed to perfect the theoretical framework, and to study how to accurately measure and control the electromagnetic fields inside cells. We should use existing and newly developed technologies to improve our experimental methods and increase the consistency and replicability of data.

References

[1] Li, J. (2022, December 27). Telemedicine And Telehealth In 2023 And Beyond: From Leveling Out To Leveling Up. Forbes.

[2] ZHANG Xiaodi, ZHANG Shurong, ZHANG Hui. Effect of intercellular coupling and electromagnetic field on multicellular calcium oscillation [J].Chinese Journal of Medical Physics,2009,26(04):1331-1334.

[3] ZHANG Hui, ZHANG Xiaodi, ZHANG Shurong, et al. Molecular mechanism analysis of biological effects of electromagnetic field [J].Chinese Journal of Tissue Engineering Research and Clinical Rehabilitation,2008(04):643-646..

[4] Rouleau, N., & Dotta, B. T. Electromagnetic fields as structure-function zeitgebers in biological systems: environmental orchestrations of morphogenesis and consciousness [J]. Frontiers in integrative neuroscience, 2014, 8, 84.

[5] LU Dongfang, YUAN Linqing, WANG Xuan, et al. Inhibition of very low frequency electromagnetic field combined with static magnetic field on tumor cell proliferation and possible mechanism[J].Tumor,2019,39(12):973-984..

[6] Maziarz, A., Kocan, B., Bester, M. et al. How electromagnetic fields can influence adult stem cells: positive and negative impacts [J]. Stem Cell Res Ther 7, 54 (2016).

[7] Lei Zhang, Yubin Hou, Zhiyuan Li, et al. 27 T ultra-high static magnetic field changes orientation and morphology of mitotic spindles in human cells [J]. eLife 2017,6:e22911.

[8] Huston, R. Using the Electromagnetics of Cancer’s Centrosome Clusters to Attract Therapeutic Nanoparticles [J]. Advances in Bioscience and Biotechnology, 2015,6, 172-181.

[9] WANG Yanhong,WANG Lei,WU Jingzhi. Electromagnetic field action generated at nanoscale by neural microtubule vibration [J].Acta Physica Sinica,2021,70(15):351-357.

[10] Ma, L., Tian, S., Zhang, H-L., Wang, J-Y., Wang, J-W., Yan, H-L., Hu, X-G., Shao, Q., & Guo, J-M. (2023). Transcriptomic and metabolomic studies on the protective effect of molecular hydrogen against nuclear electromagnetic pulse-induced brain damage. Frontiers in Public Health, 11, 1103022. doi: 10.3389/fpubh.2023.1103022

[11] Jin Huanrong, Xie Huaijiang, Zhao Su, et al. Effect of ELF electromagnetic field on antioxidant system of rat brain tissue [J].Industrial Hygiene and Occupational Diseases,2005(04):203-205.

[12] L. Huston, R. A Review of Electromagnetic Activity in Cellular Mechanics [J]. Advances in Bioscience and Biotechnology, 2016,7, 360-371.

[13] WU Lin, SONG Lun. Research progress on the effect of electromagnetic radiation on microglial function [J].Military Medicine,2019,43(10):792-796.

[14] Zhao, Y., Zhan, Q. Electric fields generated by synchronized oscillations of microtubules, centrosomes and chromosomes regulate the dynamics of mitosis and meiosis. Theor Biol Med Model 9, 26 (2012).

[15] Nygren, J., Adelman, R. A., Myakishev-Rempel, , et al. Centrosome as a micro-electronic generator in live cell [J]. Bio Systems, 2020,197, 104210.

[16] SUN Chengxun, ZHU Baoyu, GAO Yang, et al. Research progress on ELF electromagnetic field and apoptosis [J].Industrial Hygiene and Occupational Diseases,2016,42(01):66-70.

[17] Rosati, B., & McKinnon, D. Regulation of Ion Channel Expression. Circulation Research, 2004, 94, 874-883.

[18] GUO Yusong. Activation and regulation mechanism of Piezo ion channel in mechanoreceptors [J].Chinese Journal of Nature,2022,44(03):182-194.

[19] LIU Chaohui, DENG Yelong, KONG Lingjun, et al. Research progress on the effect of pulsed electromagnetic field on osteogenic differentiation of bone marrow mesenchymal stem cells [J].Journal of Traditional Chinese Medicine Orthopedics,2023,35(04):38-42.

[20] CHEN Danying, ZHANG Lixin. Research progress on the mechanism and parameters of magnetic field promoting nerve repair [J].Chinese Journal of Medical Physics,2018,35(07):822-827.