African Journal of
Biochemistry and Molecular Biology Research

ISSN : 1595-7926

Index: Harvard, Boston, Sydney University, Dimensions, Lens, ResearchGet Scilit, Semantic, Google Scholar, Base etc

https://doi.org/10.58578/AJBMBR.v2i2.5653

Cell Dynamics: Mechanisms, Technologies, and Applications in Health and Disease

Muhammad Akram[1], Isaac John Umaru[2], Abid Mahmood[3], Mohammed Khudhair Hasan[4], Hind A. Abdulghafoor[5], Fahad Said Khan[6], Fethi Ahmet Ozdemir[7], Gaweł Sołowski[8], Jaouher Ben Ali[9], Jehan Mohammad Al-Musawi[10]

[1,3]Government College University Faisalabad, Pakistan; [2]Federal University Wukari Taraba State, Nigeria; [4]Al Manara College for Medical Sciences, Maysan, Iraq; [5]University of Fallujah, Iraq; [6]University of Poonch Rawalakot, Azad Jammu and Kashmir, Pakistan; [7,8]Bingol University, Bingol, Türkiye; [9]University of Tunis, Tunisia; [10]University of Kufa, Najaf, Iraq

makram_0451@yahoo.com

Article Info:

Submitted:	Revised:	Accepted:	Published:
Apr 5, 2025	Apr 20, 2025	May 2, 2025	May 7, 2025

Abstract

The intricate and well-coordinated activities of cells in response to both internal and external stimuli are referred to as cell dynamics. These behaviors help living things grow, differentiate, maintain, and adapt. Using a variety of interdisciplinary techniques from molecular biology, biophysics, computational modeling, and live-cell imaging, this field examines the dynamic processes that control cell morphology, intracellular transport, cytoskeletal reorganization, signal transduction, and cell motility. The capacity of cells to alter their structure and function in real time, allowing for quick reactions to changes in the environment, damage, or developmental signals, is a key component of cell dynamics. The complex coordination of cytoskeletal filaments, vesicle trafficking channels, and signaling networks that underpin activities including mitosis, migration, immunological surveillance, and synaptic plasticity has been made visible by developments in high-resolution

AJBMBR Journal is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License

imaging and single-cell analysis. Recent research has demonstrated that cellular activities incorporate stochastic fluctuations, spatial compartmentalization, and emergent features resulting from the combined actions of molecular complexes, in addition to deterministic biochemical routes. It has been demonstrated that the mechanical characteristics of the cellular microenvironment, such as the extracellular matrix composition and substrate stiffness, are essential for regulating dynamic cellular responses, especially during wound healing, tissue formation, and cancer progression. Additionally, the enormous datasets produced by live-cell imaging and omics technologies are being decoded more and more using computational models and artificial intelligence tools, which offer fresh perspectives on the temporal and spatial control of cellular activities. In addition to expanding our understanding of basic cell biology, an understanding of cellular dynamics may help develop therapeutic approaches that target dysregulated cellular activities in conditions including cancer, dementia, and immunological disorders. In order to anticipate cellular outcomes and manipulate cell destiny for applications in synthetic biology and regenerative medicine, it will be crucial to combine quantitative modeling with experimental data as we continue to clarify the fundamentals of cellular structure and adaptability.

Keywords: Cellular dynamics, Intracellular transport, Membrane trafficking, Spatial-temporal regulation, Cell division

Introduction

Cells may quickly alter their metabolism, gene expression, cytoskeleton and cell shape, membrane dynamics, and behavior in response to signals from hormones, growth factors, nearby cells, or the extracellular matrix. For instance, the actin, microtubule, and intermediate filament cytoskeletons dynamically reorganize in response to external signals during cell migration. This is synchronized with membrane trafficking events that bring new membranes to the leading edge and internalize adhesive receptors from the trailing cell (Merindol et al.,2017).

Cellular function in all cells depends on the precise delivery of transporters, receptors, secretory, and endocytic cargo to the right location. Many pathogenic bacteria alter the host cell's cytoskeleton or membrane dynamics in order to create a reproductive niche, and many of these mechanisms are disturbed or dysregulated in human illness. The Department of Cell Biology employs a variety of model systems, including mice, Drosophila, and

cultured cells, to investigate cellular dynamics. Our objective is to see and understand cellular activities in real time and at high resolution using state-of-the-art imaging, biochemical, biophysical, and genetic techniques. (Renaud et al.,2016). Our goal is to clarify the fundamental factors and processes that work together to shape cell activity. These investigations, which center on basic cellular functions, are also crucial for comprehending how disruptions change their trajectory and might result in illness. (Sturmberg et al.,2015). The foundation of both anatomy and physiology is cell dynamics, which provides a profound comprehension of the complex systems that underpin life. (Barredo et al.,2003).

Intracellular transport

For cells to operate properly, intracellular transport through membrane-bound transporters is necessary. For instance, it carries freshly made proteins to their destination via the Golgi complex and the endoplasmic reticulum (ER), destruction, and membrane expansion during cell division. Although the main emphasis of this paper is not intracellular trafficking, we think a quick overview of the subject is useful to comprehend our CLEM approach. Numerous trafficking channels with various start and end stations are present in the cell. To attain specificity, the majority of trafficking process phases must be strictly managed (Jones et al 2003). Vesicles deliver proteins and packaged following post-translational modification in the Golgi apparatus. Intracellular transport mechanisms are crucial for transporting important proteins to certain anatomical and functional regions (such as dendrites, axons, and synaptic terminals), where comparatively few proteins are generated, since neurons have the most complicated geometries of any cell type. Although there is mounting evidence that some proteins are produced locally in spines, dendrites, and even axons and terminals, the main Cell bodies are the locations of neuronal protein synthesis; axons and nerve terminals in particular mainly depend on this source for the steady flow of certain proteins that enable them to carry out their regular tasks. Proteins and packed cargo are transported to particular locations via axonal transport systems, which developed to carry necessary components to the farthest reaches of nerve cells (Brown et al 2022). At first, these systems were separated according to movement direction and speed (slow, middle, or quick). There is no one mechanism that can explain the intricate process of membrane-forming lipids' intracellular transit. Although a number of

lipid transport channels and processes have been discovered, it is still unclear how they move throughout cells in contrast to protein transport.

All lipid transport pathways and processes must be identified, and the significance of each step in determining and controlling the lipid composition of particular membranes must be comprehended. Determining the function of lipid production and degradation at particular places is also necessary to comprehend the control of membrane lipid composition. Further knowledge of protein trafficking and the mechanics of vesicle budding and fusion will highlight the significance of vesicular transport routes for lipid transportation. When abnormalities in these trafficking routes are connected to illness, interest in lipid transport will grow. (Appert-Rolland et al.,2015).

Membrane trafficking

The wide range of proteins found in plant genomes that are involved in the membrane system and vesicular activities, along with the fact that these proteins differ from those of other kingdoms, indicate that the membrane system of plants is far more sophisticated than that of unicellular yeast. This implies that the system has changed to accommodate the cellular tactics that help the plant cell function at its best (Sarkar et al 2009). In recent the several membrane compartments and the roles that each one plays in the general metabolism of cells. The research papers and the Updates both show how busy and dynamic membrane trafficking is in the field of plant science. We hope that this collection will be useful to readers study of this field. Future developments in this field are expected to include the use of cutting-edge proteomic techniques as well as the exploration of genomic and transcriptomic databases. Examples of this are seen in the Update by, which examines current developments in the field, and the study report by membrane system may be assigned to organelles more precisely. Numerous investigations and updates have shown that it is not possible to assume that the function of animal membrane proteins or yeast's plant equivalents is the same. Therefore, to precisely understand the biological significance of the membrane system and its constituent parts, in-depth genetic alterations, biochemical investigation, and sophisticated imaging are essential. (Berón et al.,1995)

Spatial-temporal regulation

Pathogen exposure frequently initiates the formation of salicylic acid (SA), a plant defense signal, by transcriptionally activating the gene for the crucial SA-synthesis enzyme, ICS1. Therefore, it is unknown how different pathogen signals lead to the creation of SA in local and systemic tissues, as well as during different immune responses. Two transcription factors (TFs) were identified in our study to fill this knowledge gap: one is required for the circadian oscillation of Numerous TFs regulate SA biosynthesis both geographically and temporally, according to our findings. Stomata may swiftly close after an attack to stop viruses from entering. The second TF discovered, CHE, is a central circadian clock oscillator that is required for the daily oscillation of SA levels as well as pathogen-induced SA synthesis in systemic tissues during SAR (Zhang et al 2019). CHE may possibly regulate ICS1 through the known transcriptional activators protein 60g (CBP60g) and systemic acquired resistance deficiency 1 (SARD1), as the che-2 mutant hinders the activation of these TF genes. By demonstrating that many TFs regulate SA biosynthesis in both place and time, our study closes a gap in the signal transduction route between pathogen detection and SA production. The lowering of endogenous SA in plants with high baseline SA levels, such rice and potatoes, also significantly reduces their resistance to infections, even if pathogen infection does not generate SA in these plants. More recently, it has been shown that SA plays a role in stomatal immunity, which is the mechanism by which the host receptor FLAGELLIN-SENSING shuts stomata to keep bacterial pathogens out of plants after detecting bacterial flagellin. (Tu et al.,2020)

Cell division

In unicellular creatures, cell division is the process of reproduction; in multicellular animals, it is the process of tissue formation and maintenance. Since eukaryotes depend on interactions between several cell types to live, maintaining a balanced distribution of cell types is essential.

The tightly controlled process of cell multiplication makes this possible. All multicellular organisms use similar fundamental processes to control the development and division of their various cell populations. The majority of bodily tissue balance. Since many cell types

in adults require constant replacement, the majority of cell division concentrates on tissue renewal rather than expansion (Leblond et al 1956).

For example, skin cells are constantly being destroyed and replaced; instead of adult, differentiated cells reproducing, juvenile stem cells multiply to restore the population. After injury, mature cells in other cells, such as the liver's, can continue divide to promote growth or regeneration. Contrary to these patterns, certain cell types are either incapable of dividing capacity to replace diseased or damaged cells is significantly reduced in a number of tissues. These tissues include, for example, mammalian lens cells, heart muscle, and nerve cells in the central nervous system. This is a complex problem since DNA molecules are so lengthy. With over 100 million nucleotides in each strand, each human chromosome is composed of a long double coil, or helix (see The Nucleus above). DNA polymerases are complicated enzymes that start DNA replication, also known as DNA duplication. They read the nucleotide sequences that are linked to create the DNA strands as they go along the molecule. As a result, every DNA double helix strand serves as a template, dictating the nucleotide structure of a freshly formed strand. The two DNA strands are unwound by enzymes known as helicases, and other proteins attach to the split strands to stabilize them and stop them from re-pairing. Additionally, when DNA is tightly twisted into a chromatin fiber, these enzymes have the ability to unwind and untangle it. (Harashima et al.,2010)

Conclusion

Cellular dynamics is defined as the response and adaptive behavior of a cell which is necessary for development, repair, and survival. This includes intracellular transport, membrane trafficking, cytoskeletal rearrangement, and signal transduction. Molecular biology, biophysics, and live cell imaging techniques have demonstrated how molecular machinery orchestrates cell functions in a given space and time. Acquiring knowledge about these processes aids in the understanding of the ways in which disruptions lead to cancer, autoimmune disorders, and neurodegenerative diseases. A combination of experimental and computative techniques can precisely control cellular activity which can be manipulated for the advancement of therapies, regenerative medicine, and synthetic biology.

References

Appert-Rolland, C., Ebbinghaus, M., & Santen, L. (2015). Intracellular transport driven by cytoskeletal motors: General mechanisms and defects. Physics Reports, 593, 1-59.

Barredo, J. I., Kasanko, M., McCormick, N., & Lavalle, C. (2003). Modelling dynamic spatial processes: Simulation of urban future scenarios through cellular automata. Landscape and Urban Planning, 64(3), 145-60.

Berón, W., Alvarez-Dominguez, C., Mayorga, L., & Stahl, P. D. (1995). Membrane trafficking along the phagocytic pathway. Trends in Cell Biology, 5(3), 100-4.

Brown, A. (2022). Axonal transport. In Neuroscience in the 21st Century: From Basic to Clinical (pp. 607-652). Springer International Publishing.

Harashima, H., & Schnittger, A. (2010). The integration of cell division, growth and differentiation. Current Opinion in Plant Biology, 13(1), 66-74.

Jones, A. T., Gumbleton, M., & Duncan, R. (2003). Understanding endocytic pathways and intracellular trafficking: A prerequisite for effective design of advanced drug delivery systems. Advanced Drug Delivery Reviews, 55(11), 1353-7.

Leblond, C. P., & Walker, B. E. (1956). Renewal of cell populations. Physiological Reviews, 36(2), 255-76.

Merindol, R., & Walther, A. (2017). Materials learning from life: Concepts for active, adaptive and autonomous molecular systems. Chemical Society Reviews, 46(18), 5588-619.

Renaud, J. P., Chung, C. W., Danielson, U. H., Egner, U., Hennig, M., Hubbard, R. E., & Nar, H. (2016). Biophysics in drug discovery: Impact, challenges and opportunities. Nature Reviews Drug Discovery, 15(10), 679-98.

Sarkar, P., Bosneaga, E., & Auer, M. (2009). Plant cell walls throughout evolution: Towards a molecular understanding of their design principles. Journal of Experimental Botany, 60(13), 3615-35.

Sturmberg, J. P., Bennett, J. M., Picard, M., & Seely, A. J. (2015). The trajectory of life: Decreasing physiological network complexity through changing fractal patterns. Frontiers in Physiology, 6, 169.

Tu, Y., Peng, B., Wei, G., Elahi, E., & Yu, T. (2019). Regional environmental regulation efficiency: Spatiotemporal characteristics and influencing factors. Environmental Science and Pollution Research, 26, 37152-61.

Zhang, J., Ren, Z., Zhou, Y., Ma, Z., Ma, Y., Hou, D., Xu, Z., & Huang, X. (2019). NPR1 and redox rhythm: Connections between circadian clock and plant immunity. International Journal of Molecular Sciences, 20(5), 1211.