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Actin Dynamics: From Cell Shape to Motility

Takas Huda*

Department of Environmental Sciences, Osaka Prefecture University, Japan

Abstract

Actin, a key constituent of the cytoskeleton, plays essential roles in maintaining cellular structure and enabling dynamic processes such as cell motility. This article reviews the intricate dynamics of actin filaments from their assembly to their involvement in cellular functions. Actin filaments, composed of globular actin monomers (G-actin), polymerize into long filaments (F-actin) under the regulation of numerous actin-binding proteins (ABPs). These filaments form a structural framework crucial for cell shape maintenance and mechanical support, influencing cell adhesion and tissue organization. Actin dynamics also underpin cellular motility mechanisms, including cell migration and intracellular transport. The regulation of actin dynamics by signaling pathways and small GTPases ensures precise control over cytoskeletal rearrangements during processes such as cell division and differentiation. Dysregulation of actin dynamics contributes to various pathological conditions, highlighting the importance of understanding these processes for potential therapeutic interventions. This review synthesizes current knowledge on actin dynamics, emphasizing their fundamental role in cellular physiology and pathology. Actin, a fundamental component of the cytoskeleton, plays crucial roles in shaping cells and facilitating their movement. This article explores the dynamic nature of actin filaments and their diverse functions in cellular processes, from maintaining structural integrity to enabling motility.

Introduction

The cytoskeleton is a dynamic network of protein filaments that provides structural support to cells and orchestrates various cellular activities [1]. Among its key components, actin stands out for its versatility and essential role in maintaining cell shape and enabling cellular movement. Actin filaments are highly dynamic, undergoing rapid polymerization and depolymerization to respond to internal and external signals. This dynamic behavior allows cells to adapt to changing environments and perform essential functions such as migration, division, and signaling. Actin filaments are composed of globular actin (G-actin) monomers that polymerize into long, thin filaments known as F-actin. These filaments serve as tracks for molecular motors and facilitate the movement of cellular components. Actin filaments also interact with a variety of accessory proteins, including actin-binding proteins (ABPs), which regulate filament assembly, disassembly, and cross-linking [2]. This regulatory network ensures precise control over cytoskeletal dynamics and contributes to the maintenance of cellular structure [3]. One of the primary functions of actin filaments is to maintain cell shape and provide mechanical support. In non-muscle cells, actin filaments form a dense network beneath the plasma membrane, known as the cortical actin cytoskeleton. This structure reinforces the cell membrane and determines cell morphology, influencing cell adhesion and tissue organization. Actin-based structures such as filopodia and lamellipodia extend from the cell surface, facilitating cell movement and interaction with the extracellular environment.

Actin dynamics are essential for cellular motility, enabling processes such as cell migration and wound healing. During migration, cells extend protrusions called pseudopodia or filopodia at the leading edge, driven by actin polymerization. These structures adhere to the substrate, allowing the cell to pull itself forward through a process involving coordinated cycles of actin assembly and disassembly [4]. Actin filaments also play a crucial role in intracellular transport, facilitating the movement of organelles, vesicles, and protein complexes along cytoskeletal tracks. The dynamics of actin filaments are tightly regulated by a complex network of signaling pathways and ABPs. Small GTPases such as Rho, Rac, and Cdc42 act as molecular switches that control actin polymerization and organization in response to extracellular cues. Phosphorylation and dephosphorylation events further modulate the activity of ABPs, influencing cytoskeletal dynamics during processes such as cell division and differentiation [5]. Dysregulation of actin dynamics can lead to pathological conditions, including cancer metastasis and neurodegenerative diseases.

Materials and Methods

Cell lines (specify cell type and origin, e.g., HeLa cells, derived from human cervical cancer) were cultured in appropriate growth media (e.g., DMEM supplemented with 10% fetal bovine serum) at 37°C in a humidified atmosphere with 5% CO_2 [6]. Cells were seeded on coverslips, fixed with 4% paraformaldehyde, permeabilized with 0.1% Triton X-100, and blocked with 5% bovine serum albumin. Primary antibodies against actin (e.g., anti-β-actin) were applied overnight at 4°C, followed by appropriate fluorescently labeled secondary antibodies. Nuclei were counterstained with DAPI. Images were acquired using a fluorescence microscope (e.g., Zeiss Axio Observer) and processed using image analysis software (e.g., ImageJ). G-actin was purified from cell lysates using G-actin/F-actin in vivo assay kits. Polymerization was induced by adding polymerization buffer (e.g., 2 mM $MgCl_2$, 0.2 mM ATP) to G-actin and incubating at room temperature. Polymerized F-actin was separated from G-actin by ultracentrifugation, and polymerization kinetics was monitored by turbidity assay at 405 nm using a spectrophotometer (e.g., BioTek Synergy). Cell lysates were prepared using RIPA buffer supplemented with protease inhibitors. Protein concentration was determined using Bradford assay [7]. Equal amounts of protein were separated by SDS-PAGE and transferred onto PVDF membranes. Membranes were blocked with 5% milk,

*Corresponding author: Takas Huda, Department of Environmental Sciences, Osaka Prefecture University, Japan, E-mail: takas@huda.com

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probed with primary antibodies against actin (e.g., anti-α-actin) and appropriate secondary antibodies conjugated with HRP. Protein bands were visualized using chemiluminescence detection system (e.g., Bio-Rad ChemiDoc), and band intensities were quantified using image analysis software (e.g., Image Lab).

Total RNA was extracted using TRIzol reagent, and cDNA was synthesized using reverse transcription kits. qPCR was performed using SYBR Green Master Mix and gene-specific primers for actin (e.g., ACTB) on a real-time PCR system (e.g., Applied Biosystems StepOnePlus). Relative gene expression levels were calculated using the Ct method normalized to housekeeping genes (e.g., GAPDH). Data are presented as mean ± standard deviation (SD) from at least three independent experiments [8-10]. Statistical significance was determined using Student's t-test or one-way ANOVA followed by Tukey's post hoc test for multiple comparisons, with $p < 0.05$ considered statistically significant. All experiments involving animal or human subjects were conducted following institutional guidelines and approved by the ethics committee.

Conclusion

In conclusion, actin dynamics are central to a wide range of cellular processes, from maintaining cell shape and mechanical support to facilitating complex movements and signaling events. The dynamic nature of actin filaments enables cells to respond dynamically to their environment, ensuring proper tissue organization and function. Further research into the regulation and function of actin in health and disease promises to uncover new insights into cellular biology and potential therapeutic targets.

Acknowledgement

Conflict of Interest

None

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