Cytoskeleton: Dynamics, Mechanics, and Disease

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Received: 01-Oct-2025; **Accepted:** 10-Nov-2025; **Published:** 10-Nov-2025

Introduction

Understanding the fundamental mechanisms driving cellular reorganization is key to cell biology. Here, research illuminates the structural underpinnings of microtubule severing, a vital process for cellular adaptation. It meticulously details how the AAA+ ATPase spastin actively remodels microtubules, offering new and significant insights into the mechanical forces and specific conformational changes that are intricately involved in this fundamental cytoskeletal activity, essential for maintaining cellular function and integrity [1].

Moving into the realm of cellular pathology, particularly cancer, studies reveal how these cells exhibit a unique mechanical memory. This memory significantly influences their ability to migrate and invade surrounding tissues, a phenomenon primarily driven by the active and constant remodeling of the actin cytoskeleton. What this really means is that past mechanical cues can dramatically modulate future cellular responses, creating lasting changes within the actin network that drive disease progression [2].

Epithelial cell polarity, a critical feature for tissue organization and function, depends on precise mechanical regulation. This work elucidates how the coordinated action of Myosin II and actin network flow collaboratively establishes asymmetric cortical tension. Such tension is crucial for enabling epithelial cells to maintain their distinct polarized states. It provides a robust mechanical explanation for how cells meticulously organize their internal structure to execute directional functions effectively, impacting processes from tissue development to wound healing [3].

The ability of cells to perceive and respond to their mechanical environment, known as mechanosensation, is paramount for tissue homeostasis. This article explores how the actin cortex, the dynamic network underlying the plasma membrane, senses mechanical cues. It achieves this through specialized cadherin-based adhesion complexes, effectively translating external physical forces into intricate intracellular signals. It highlights the indispensable role of these sophisticated structures in cellular mechanotransduction and their broader contribution to overall tissue organization and integrity [4].

Beyond actin and microtubules, intermediate filaments also play unexpected, yet crucial, roles in cellular mechanics. This research uncovers a novel function for intermediate filaments in regulating epithelial cell mechanics. They achieve this by specifically modulating Myosin II activity, demonstrating a sophisticated interplay between different cytoskeletal components. This interaction contributes significantly to cellular stiffness and resilience, which are critical for maintaining the architectural integrity of tissues and enabling cells to effectively respond to various forms of mechanical stress [5].

Cellular signaling pathways often converge on the cytoskeleton to dictate cell behavior. This review comprehensively discusses the intricate mechanisms by which G-protein-coupled receptors (GPCRs), a large family of cell surface receptors, orchestrate the dynamic organization of the actin cytoskeleton. It emphasizes how diverse GPCR signaling pathways coalesce to modulate key aspects of actin polymerization and the overall network architecture, profoundly influencing cell shape, migration patterns, and adhesion properties, fundamental for development and disease [6].

Centrosome integrity and microtubule organization are indispensable for proper cell division and overall cellular architecture. This study reveals the critical role of the nucleoporin Nup358/RanBP2 in maintaining the structural integrity of the centrosome and regulating microtubule organization, especially during the intricate stages of cell division. It clarifies how a component typically associated with the nuclear pore complex can significantly influence cytoplasmic cytoskeletal architecture, thereby highlighting a novel and unexpected regulatory nexus [7].

Cell migration, a complex and highly coordinated process, necessitates a finely tuned interplay between internal cellular components. This article explores the intricate interplay between actin dynamics and membrane dynamics in controlling directed cell migration. What this really means is that the actin cytoskeleton's constant reorganization is tightly coupled with critical membrane remodeling processes, such as endocytosis and exocytosis, to facilitate efficient and purposeful cell movement within tissues [8].

The broad significance of cytoskeletal dynamics extends to their profound involvement in various human diseases. This review delves into the complex roles of cytoskeletal dynamics and their intricate regulatory mechanisms within the context of pathology. It emphasizes how the dysregulation of actin, microtubule, and intermediate filament networks consistently contributes to both the initiation and progression of a wide array of pathologies, encompassing cancer, various neurological disorders, and even infectious diseases, positioning the cytoskeleton as a key therapeutic target [9].

Traditionally viewed as cytoplasmic structures, the actin cytoskeleton and microtubules possess surprising influence beyond the cytoplasm. This article explores the unexpected contributions of both the actin cytoskeleton

Cite this article: Robinson G,(2025) Cytoskeleton: Dynamics, Mechanics, and *Disease. jmcb* 07: 175. DOI: 1037532.jmcb.2025.7.4.175

and microtubules to the dynamic organization occurring within the nucleus itself. It demonstrably shows how these cytoplasmic filaments can significantly influence nuclear shape, chromatin organization, and even gene expression, revealing a deeper and more integrated level of cellular control and function [10].

Description

The dynamic nature of the cellular cytoskeleton is fundamental to numerous biological processes, from structural integrity to disease progression. Research has meticulously detailed the structural basis for microtubule severing, an essential process for cellular reorganization. This work highlights how the AAA+ ATPase spastin actively remodels microtubules, offering fresh insights into the mechanical forces and conformational changes involved in this fundamental activity [1]. Complementing this, other studies investigate how mechanical forces profoundly shape cell behavior. For example, cancer cells exhibit a distinct mechanical memory, which significantly influences their migration and invasion. This phenomenon is directly linked to active remodeling of the actin cytoskeleton, suggesting that prior mechanical cues can modulate future cellular responses through lasting changes in the actin network [2]. This intricate link between cellular mechanics and disease progression underscores the importance of cytoskeletal regulation.

Beyond pathological contexts, the actin cytoskeleton plays a crucial role in establishing fundamental cellular properties like polarity. The coordinated action of Myosin II and the dynamic flow of the actin network are essential for generating asymmetric cortical tension, a key factor in epithelial cell polarity [3]. This provides a concrete mechanical explanation for how cells organize their internal structures to perform specific directional functions. Furthermore, the cell's ability to sense its external mechanical environment is largely mediated by the actin cortex. This structure senses mechanical cues through cadherin-based adhesion complexes, effectively translating external forces into intracellular signals. This mechanism is critical for cellular mechanotransduction and proper tissue organization, illustrating the sophisticated sensory capabilities of the cell [4].

While actin and microtubules are widely recognized, intermediate filaments also contribute significantly to cellular mechanics. Recent findings reveal a novel role for intermediate filaments in regulating epithelial cell mechanics by tuning Myosin II activity. This interplay directly impacts cellular stiffness and resilience, which are vital for maintaining tissue integrity and responding effectively to mechanical stress [5]. The regulation of the cytoskeleton is also tightly integrated with various signaling pathways. G-protein-coupled receptors (GPCRs), for instance, orchestrate the dynamic organization of the actin cytoskeleton. A comprehensive review emphasizes how diverse GPCR signaling pathways converge to modulate actin polymerization and network architecture, thereby influencing cell shape, migration, and adhesion [6]. In another fascinating discovery, the nucleoporin Nup358/RanBP2, typically associated with the nuclear pore complex, is shown to critically control centrosome integrity and regulate microtubule organization, especially during cell division. This clarifies how a nuclear component can exert influence over cytoplasmic cytoskeletal architecture, highlighting a novel regulatory nexus [7].

The intricate coupling between different cellular systems is also evident in cell migration. Here's the thing: actin dynamics and membrane dynamics are tightly interwoven to control cell migration. The actin cytoskeleton's reorganization is closely coupled with membrane remodeling processes, such as endocytosis and exocytosis, which collectively facilitate directed cell movement [8]. Perhaps most surprisingly, the influence of the cytoskeleton extends even into the nucleus itself. Both the actin cytoskeleton and microtubules contribute to the dynamic organization within the nucleus. This unexpected role shows how these cytoplasmic filaments can influence nuclear shape, chromatin organization, and even gene expression, revealing a deeper level of cellular integration and control than previously understood [10].

Ultimately, understanding these dynamic processes is crucial because dysregulation of cytoskeletal dynamics is implicated in a wide spectrum of diseases. A comprehensive review delves into the complex roles of cytoskeletal dynamics and their regulatory mechanisms in various pathologies. It underscores how dysregulation of actin, microtubule, and intermediate filament networks actively contributes to the initiation and progression of conditions including cancer, neurological disorders, and infectious diseases, positioning the cytoskeleton as a significant area for therapeutic intervention [9].

Conclusion

The cytoskeleton, composed of actin filaments, microtubules, and intermediate filaments, is central to virtually all cellular functions, governing structure, movement, and signaling. Recent research significantly advances our understanding of these dynamics and their implications for health and disease. Here, the structural basis of microtubule severing by AAA+ ATPase spastin has been elucidated, shedding light on cellular reorganization processes driven by mechanical forces and conformational changes. Studies also reveal the profound impact of cytoskeletal mechanics on cell behavior. Cancer cells exhibit a mechanical memory, where active actin remodeling dictates migration and invasion, demonstrating how past mechanical cues influence future cellular responses. The coordinated action of Myosin II and actin network flow is crucial for establishing asymmetric cortical tension, which is essential for epithelial cell polarity and directional cellular functions. Furthermore, the actin cortex's ability to sense mechanical cues through cadherin-based adhesion complexes highlights its role in mechanotransduction and tissue organization. Intermediate filaments are not just passive structural elements; they actively control epithelial cell mechanics by modulating Myosin II activity, contributing to cellular stiffness and resilience, vital for tissue integrity. Regulation extends to G-protein-coupled receptors, which orchestrate actin cytoskeleton organization, influencing cell shape, migration, and adhesion through diverse signaling pathways. Microtubules also play a vital role in centrosome integrity and organization during cell division, influenced by nuclear pore complex components like Nup358/RanBP2. The interplay between actin and membrane dynamics is fundamental for cell migration, with cytoskeleton reorganization tightly coupled to processes like endocytosis and exocytosis. Remarkably, both the actin cytoskeleton and microtubules contribute to the dynamic organization within the nucleus, affecting nuclear shape, chromatin organization, and gene expression. The dysregulation of these cytoskeletal networks is a common thread in various diseases, including cancer and neurological disorders, underscoring the broad pathological consequences of disrupted cytoskeletal dynamics.

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References

1. Igor Z, Jennifer LS, Michael P. Structural basis for microtubule severing by the AAA+ *ATPase spastin. Science.* 2024;384:799-805.
2. Yi L, Rui S, *Ruyi Z. Mechanical memory through active actin remodeling in cancer cells. Nat Cell Biol.* 2023;25:1680-1691.
3. Xiaomeng S, Yajie P, Rui M. Myosin II-driven actin network flow generates asymmetric cortical tension for epithelial cell polarity. *Nat Cell Biol.* 2023;25:1221-1234.
4. Matthew JH, Philip RL, Valerie V. Mechanosensation of the actin cortex via cadherin-based adhesion complexes. *Curr Opin Cell Biol.* 2023;80:102170.
5. Jia L, Xiaoying D, *Yingjie Y. Intermediate filaments control epithelial cell mechanics by tuning myosin II activity. Nat Cell Biol.* 2023;25:228-241.
6. Adrien B, Angela DA, Dalila G. Regulation of actin cytoskeleton organization by G-protein-coupled receptors. *Trends Cell Biol.* 2023;33:1003-1014.
7. Jingjing M, Yajie P, Shuang Z. The control of centrosome integrity and microtubule organization by the nucleoporin Nup358/RanBP2. *Nat Cell Biol.* 2023;25:1251-1262.
8. Gabriele S, Marta L, *Luca L. Regulation of actin dynamics in cell migration through coupling with membrane dynamics. Cells.* 2022;11:742.
9. Chao H, Wenli L, *Huamei Z. Cytoskeletal dynamics and regulation in disease. J Cell Sci.* 2023;136:jcs260596.
10. Nicolas V, Léa C, Pierre-François *L. The actin cytoskeleton and microtubules contribute to the dynamic organization of the nucleus. Mol Cell Biol.* 2022;42:e0028222.

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