Mitosis and microtubules: Orchestrating accurate cell division.

Jose Celis*

Centro de Biología Molecular "Severo Ochoa", CSIC and Universidad Autónoma de Madrid, Madrid, 28049, Spain

Introduction

Cell division is a fundamental process that underlies growth, development, tissue repair, and reproduction in all living organisms. One of the key players in this intricate dance of cellular division is mitosis, a tightly regulated process that ensures the faithful distribution of genetic material to daughter cells. At the heart of mitosis are microtubules, dynamic protein filaments that act as the scaffolding for cell division, orchestrating its accuracy and fidelity. Mitosis is a highly coordinated process involving a series of carefully choreographed steps. It ensures that each daughter cell receives an identical set of chromosomes, thereby maintaining genetic stability. This process is essential for growth, repair, and maintenance of multicellular organisms. Mitosis consists of several distinct phases: prophase, metaphase, anaphase, and telophase [1].

Microtubules are integral to mitosis, serving as the tracks along which chromosomes move during cell division. They are long, cylindrical filaments composed of tubulin protein subunits. These filaments exhibit dynamic instability, constantly growing and shrinking, which allows them to rapidly reconfigure and participate in various cellular processes. During mitosis, microtubules form the mitotic spindle, a dynamic structure that segregates chromosomes into daughter cells. This spindle has two main components: kinetochore microtubules and astral microtubules. Kinetochore microtubules attach to specialized protein structures called kinetochores located at the centromeres of chromosomes. Astral microtubules radiate outward from the spindle poles and contribute to spindle positioning [2].

The process of mitosis begins with prophase, during which microtubules reorganize to form the mitotic spindle. The nuclear envelope dissolves, allowing microtubules to interact with chromosomes. Kinetochore microtubules attach to kinetochores, establishing a connection that will eventually separate sister chromatids. In metaphase, microtubules align chromosomes at the cell's equator, known as the metaphase plate. This alignment ensures that each daughter cell will receive an accurate set of chromosomes. The spindle checkpoint monitors this alignment and prevents progression to anaphase until all chromosomes are correctly positioned. During anaphase, the connections between sister chromatids are dissolved, and microtubules shorten, pulling the separated chromatids toward opposite poles of the cell. This precise movement guarantees that each daughter cell inherits a complete set of chromosomes. Telophase marks the near-end of mitosis. Microtubules continue to play a crucial role in this phase, aiding the reformation of the nuclear envelope around the separated sets of chromosomes. The mitotic spindle disassembles, and the microtubules are reabsorbed by the cell [3].

Though distinct from mitosis, cytokinesis is the final step of cell division. Microtubules contribute to this process as well, by aiding the formation of the contractile ring, which pinches the cell's membrane to divide it into two daughter cells. The orchestration of mitosis relies on the precise regulation of microtubule dynamics. Various proteins control microtubule assembly, stability, and interactions with other cellular components. For instance, motor proteins like kinesins and dyneins move along microtubules, assisting in chromosome segregation and spindle organization [4].

Malfunctions in mitosis and microtubule dynamics can lead to serious health issues. Uncontrolled cell division is a hallmark of cancer, and many cancer drugs target microtubules to disrupt cell division and inhibit tumor growth. Additionally, genetic disorders affecting microtubule-associated proteins can lead to developmental defects and neurodegenerative diseases. Microtubules are not static structures; they exhibit dynamic instability, a phenomenon where they alternate between phases of growth and shrinkage. This dynamic behavior is vital for their roles in cell division and other cellular processes. During growth, tubulin dimers are added to the growing end of the microtubule, extending it outward. Conversely, during shrinkage, tubulin dimers are lost from the microtubule, leading to its shortening [5].

Conclusion

Mitosis, the intricate process of cell division, relies on the dynamic nature of microtubules to ensure the accurate distribution of genetic material. The orchestration of this dance is a remarkable feat of cellular regulation, involving an array of proteins and complex interactions. Understanding the role of microtubules in mitosis not only deepens our knowledge of fundamental biology but also holds promise for medical advancements in cancer treatment and other diseases rooted in cell division dysfunction. As research continues to unravel the complexities of this elegant process, we gain insights into the very essence of life itself.

***Correspondence to:** Jose Celis ,Centro de Biología Molecular "Severo Ochoa", CSIC and Universidad Autónoma de Madrid, Madrid, 28049, Spain. E-mail: josecelis@cbm.csic.es

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