

MicroRNAs: Pivotal in Disease, Therapy, Diagnostics

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Introduction

MicroRNAs, small non-coding RNA molecules, are fundamental to biological regulation, orchestrating gene expression across a spectrum of cellular processes. Their pervasive influence extends to maintaining health and contributing to disease pathogenesis, making them an intensive area of research for their therapeutic and diagnostic potential. Understanding their intricate roles is paramount to advancing medicine.

In oncology, MicroRNAs significantly influence the efficacy of cancer immunotherapy. This occurs through their modulation of various immune checkpoints and critical signaling pathways. Their precise regulation can considerably enhance therapeutic responses, positioning MicroRNAs as promising candidates for both biomarkers and therapeutic targets aimed at improving patient outcomes and refining personalized treatment strategies [1].

Moving to the neurological domain, MicroRNAs play critical roles in the pathogenesis of debilitating neurodegenerative diseases, encompassing conditions like Alzheimer's and Parkinson's. The dysregulation of these miRNAs offers promising avenues for novel therapeutic strategies, with emerging miRNA-based approaches demonstrating substantial potential for early diagnosis and effective treatment in this challenging field [2].

In the realm of metabolic health, MicroRNAs are deeply involved in regulating complex metabolic pathways and contribute directly to the development of widespread metabolic diseases such as diabetes and obesity. The strategic targeting of specific miRNAs or their associated pathways presents significant potential for developing innovative therapeutic interventions to combat these prevalent conditions [3].

Cardiovascular well-being is also profoundly impacted by MicroRNAs, which act as key orchestrators in cardiac remodeling and repair following injury or stress. Their precise modulation offers a promising and tar-

geted strategy for developing new therapies to prevent and treat various cardiovascular diseases, including severe conditions like heart failure and myocardial infarction, aiming for improved cardiac function and patient recovery [4].

Beyond endogenous functions, MicroRNAs are central to the dynamic interplay during host-virus interactions, influencing both the intricate processes of viral replication and the robustness of host immune responses. Gaining a deeper understanding of this complex interplay provides crucial insights essential for developing innovative antiviral strategies and for creating improved diagnostic tools to detect and manage viral infections more effectively [5].

Fundamentally, MicroRNAs are essential regulators of immune cell development, differentiation, and overall function. Their fine-tuned control over gene expression pathways is absolutely critical for maintaining immune homeostasis, ensuring the immune system operates correctly, and for mounting effective responses against invading pathogens and various diseases, underscoring their vital role in immunological defense [6].

MicroRNAs also function as crucial epigenetic regulators, exerting influence over gene expression at multiple levels and consequently impacting the progression and manifestation of various human diseases. The comprehensive unraveling of these complex epigenetic mechanisms provides new and exciting avenues for developing targeted therapeutic interventions and advancing personalized medicine approaches [7].

Moreover, MicroRNAs are indispensable for normal cellular differentiation, the proper formation of organs (organogenesis), and overall developmental processes throughout an organism's life. Their dysregulation can lead to a spectrum of developmental disorders and is known to contribute significantly to the progression of numerous other diseases, underscoring their profound and fundamental biological importance across all stages of life [8].

A critical aspect in cancer therapy is drug resistance, where MicroRNAs play a significant role in mediating this challenge. They achieve this by modulating gene expression pathways involved in drug uptake, metabolism, and efflux. Targeting these specific miRNAs represents a promising and strategic approach to overcome therapeutic resistance and thereby markedly improve the efficacy of existing cancer treatments, offering hope for more successful outcomes [9].

Finally, MicroRNAs circulating freely in bodily fluids show immense potential as non-invasive biomarkers. These stable molecules can be utilized for early diagnosis, accurate prognosis, and effective monitoring of treatment response across an extensive range of human diseases. Their inherent stability and often tissue-specific expression patterns make them exceptionally valuable tools in diverse clinical settings, ushering in a new era for advanced diagnostics and patient management [10].

Description

MicroRNAs are pivotal small non-coding RNA molecules that meticulously regulate gene expression, fundamentally influencing a vast array of biological processes. Their essential roles commence early in life, being indispensable for normal cellular differentiation, proper organogenesis, and overall developmental processes [8]. Any dysregulation in their function can manifest as various developmental disorders, underscoring their crucial biological importance throughout an organism's lifespan. Beyond these developmental aspects, MicroRNAs are also fundamental regulators of immune cell development, differentiation, and overall function [6]. Their fine-tuned control over gene expression pathways is critical for maintaining robust immune homeostasis, thereby ensuring the body's defenses are both balanced and highly effective against invading pathogens and other diseases.

Their involvement extends deeply into the pathogenesis of diseases across multiple physiological systems. For example, MicroRNAs play critical roles in the progression of neurodegenerative diseases, including debilitating conditions such as Alzheimer's and Parkinson's. The precise dysregulation of these miRNAs presents promising avenues for novel therapeutic strategies, with emerging miRNA-based approaches showing substantial potential for both early diagnosis and effective treatment within this challenging medical field [2]. Similarly, MicroRNAs are deeply involved in regulating complex metabolic pathways and contribute significantly to the development of widespread metabolic diseases like diabetes and obesity. Targeting specific miRNAs or their associated pathways therefore holds considerable potential for developing innovative therapeutic interventions designed to combat these prevalent conditions [3]. In the context of cardiovascular health, MicroRNAs are key orchestrators in cardiac remodeling and repair following injury. Their precise modulation offers a highly promising strategy for developing new therapies aimed at preventing and treating various cardiovascular diseases, including severe conditions such as heart failure and myocardial infarction, with the ultimate goal of improving cardiac function and patient recovery [4].

In the complex landscape of oncology, MicroRNAs exert a profound and multifaceted impact. They significantly influence the efficacy of cancer immunotherapy by strategically modulating various immune checkpoints and critical signaling pathways. Their precise regulation can considerably enhance therapeutic responses, positioning MicroRNAs as promising candidates for both predictive biomarkers and direct therapeutic targets aimed at improving overall patient outcomes and refining personalized cancer treatment strategies [1]. Furthermore, a significant challenge in contemporary cancer treatment is the development of drug resistance, where MicroRNAs play a major and often detrimental role. They mediate this resistance by intricately modulating gene expression pathways involved in drug uptake, metabolism, and efflux. Consequently, targeting these specific miRNAs represents a promising and strategic approach to overcome therapeutic resistance and thereby markedly improve the efficacy of existing cancer treatments, offering new hope for more successful patient responses [9].

Beyond these direct disease-specific roles, MicroRNAs also function as crucial epigenetic regulators. They exert their influence over gene expression at multiple intricate levels, consequently impacting the manifestation and progression of a wide range of human diseases. The comprehensive unraveling of these complex epigenetic mechanisms provides new and exciting avenues for developing targeted therapeutic interventions and advancing personalized medicine approaches, allowing for more tailored treat-

ments [7]. Furthermore, MicroRNAs are central to the complex and dynamic interplay that occurs during host-virus interactions. They influence both the intricate processes of viral replication within host cells and the robustness of host immune responses designed to combat infection. Gaining a deeper understanding of this intricate relationship provides crucial insights essential for developing innovative antiviral strategies and for creating improved diagnostic tools to detect and manage viral infections more effectively, leading to better public health outcomes [5].

Critically, MicroRNAs circulating freely in bodily fluids show immense potential as non-invasive biomarkers. These stable molecules can be effectively utilized for early diagnosis, accurate prognosis, and efficient monitoring of treatment response across an extensive range of human diseases within diverse clinical settings [10]. Their inherent stability and often highly tissue-specific expression patterns make them exceptionally valuable tools, demonstrating their utility far beyond just therapeutic targets. This positions MicroRNAs as essential components in the future of precision medicine, offering less intrusive yet highly informative ways to assess health and disease progression.

Conclusion

MicroRNAs are pivotal small non-coding RNA molecules that orchestrate gene expression, proving essential for normal cellular development, immune system regulation, and maintaining overall biological homeostasis. Their significant impact is evident in a broad range of human diseases. For instance, they profoundly influence the efficacy of cancer immunotherapy by modulating immune checkpoints and are implicated in mediating drug resistance, suggesting their utility as targets to enhance therapeutic outcomes. Beyond cancer, MicroRNAs play critical roles in the pathogenesis of neurodegenerative diseases, including Alzheimer's and Parkinson's, and are deeply involved in metabolic disorders such as diabetes and obesity, offering new therapeutic avenues. They are also key orchestrators in cardiac remodeling and repair following injury, indicating their importance in cardiovascular health. Furthermore, MicroRNAs are central to host-virus interactions, affecting both viral replication and host immune responses, and function as crucial epigenetic regulators. Critically, MicroRNAs circulating in bodily fluids show great promise as non-invasive biomarkers for early diagnosis, prognosis, and monitoring treatment response across diverse diseases, leveraging their stability and tissue-specific expression. This comprehensive involvement highlights MicroRNAs as significant players with vast potential for both therapeutic development and diagnostic innovation in medicine.

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