RNA-based Regulation of Gene Expression: More Than Just a Messenger.

Ronald Pinhe*

Center for Research and Drug Development (NPDM), Federal University of Ceara, Fortaleza, Ceara, Brazil

Introduction

In the intricate dance of genetic information flow within cells, RNA plays a central role not only as a messenger but also as a versatile regulator of gene expression. While the classic understanding of RNA primarily revolves around its role in protein synthesis, recent discoveries have illuminated a myriad of additional functions that RNA molecules perform, influencing gene expression at multiple levels. This expanding landscape of RNA-based regulation is transforming our comprehension of cellular dynamics and has profound implications for understanding health and disease [1,2].

Traditionally, RNA has been viewed as the intermediary between DNA and protein, shuttling genetic information from the nucleus to the cytoplasm for translation. However, this narrative vastly understates the multifaceted roles that RNA molecules execute within the cell. Beyond mRNA, which encodes proteins, various types of non-coding RNAs (ncRNAs) have emerged as key players in gene regulation. These ncRNAs do not code for proteins but exert control over gene expression through diverse mechanisms.One prominent class of regulatory RNAs is microRNAs (miRNAs). MiRNAs are small RNA molecules that can bind to specific messenger RNAs, leading to their degradation or inhibition of translation. By targeting specific mRNA sequences, miRNAs act as post-transcriptional regulators, fine-tuning gene expression in response to cellular conditions. Dysregulation of miRNA expression has been implicated in various diseases, underscoring their importance as critical regulators of cellular homeostasis [3,4].

Another class of regulatory RNAs, long non-coding RNAs (lncRNAs), has gained attention for their roles in modulating gene expression through diverse mechanisms. LncRNAs can act as guides, scaffolds, or decoys, interacting with proteins or other RNAs to regulate transcriptional processes. Some lncRNAs can recruit chromatin-modifying complexes to specific genomic loci, influencing the epigenetic landscape and thereby controlling gene expression patterns over longer timescales.Moreover, emerging research highlights the significance of circular RNAs (circRNAs), a class of covalently closed circular RNA molecules that are produced by back-splicing of pre-mRNA transcripts. CircRNAs can function as sponges for miRNAs, sequestering them and preventing their interaction with target mRNAs. This sponge-like activity enables circRNAs to indirectly regulate gene expression by modulating miRNA availability within the cell [5,6].

The realm of RNA-based gene regulation extends beyond the cytoplasmic milieu into the nucleus, where various RNA species participate in transcriptional control. For instance, enhancer RNAs (eRNAs) are transcribed from enhancer regions of the genome and can regulate the activity of nearby genes. By interacting with transcription factors or chromatin-modifying complexes, eRNAs contribute to the fine-tuning of gene expression programs in response to cellular signals. The discovery of RNA interference (RNAi) mechanisms has also revolutionized our understanding of RNA-based gene regulation. RNAi pathways utilize small interfering RNAs (siRNAs) or short hairpin RNAs (shRNAs) to target and degrade specific mRNA transcripts, offering a powerful tool for experimental gene silencing and potential therapeutic interventions [7,8].

Furthermore, recent studies have illuminated the role of RNA modifications in regulating gene expression. RNA epigenetics, particularly modifications such as N6-methyladenosine (m6A) and pseudouridine, can impact RNA stability, translation efficiency, or localization, thereby modulating gene expression dynamics in response to cellular cues.The implications of RNA-based gene regulation extend far beyond fundamental biology. Dysregulation of RNA-mediated processes has been implicated in various diseases, including cancer, neurodegenerative disorders, and metabolic syndromes. Targeting specific RNA molecules or pathways holds promise for developing novel therapeutic strategies aimed at restoring cellular balance in pathological conditions [9,10].

Conclusion

In conclusion, the narrative of RNA biology has evolved from a simplistic view of RNA as a messenger to a sophisticated understanding of its diverse regulatory functions within the cell. RNA molecules, both coding and non-coding, participate in intricate networks that govern gene expression at multiple levels, from transcriptional initiation to protein translation. Unraveling these complex regulatory circuits not only deepens our understanding of cellular processes but also opens new avenues for therapeutic interventions targeting RNA-based mechanisms in health and disease. As we continue to unveil the secrets of RNA-mediated gene regulation, we are poised to witness transformative advances in biomedical research and clinical medicine.

***Correspondence to: Farsad Boroujen,** Center for Research and Drug Development (NPDM), Federal University of Ceara, Fortaleza, Ceara, Brazil. E-mail: pinheiro@gmail.com

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