Review

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Posted Date: 8 March 2024

doi: 10.20944/preprints202403.0393.v1

Keywords: DNA; Molecular Choreography; Genetic Information; Epigenetic Modifications; CRISPR-Cas9; DNA Replication; Gene Editing

 doi:10.20944/preprints202403.0393.v1

Review

Molecular Choreography of DNA: Insights and Innovations

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Abstract: The study titled "Molecular Choreography of DNA: Insights and Innovations" explores the intricate dance of DNA, shedding light on its structure, function, and regulation. This comprehensive review delves into the historical significance of DNA research, from Watson and Crick's double helix discovery to recent innovations in genomics and molecular biology. The review highlights DNA's roles in replication, repair, gene regulation, and chromatin dynamics, emphasizing the precision and complexity of its molecular choreography. Innovations like CRISPR-Cas9 gene editing and advanced sequencing technologies have revolutionized our understanding of DNA, opening new avenues for scientific exploration. This study aims to provide readers with a deeper appreciation of DNA's central role in life's choreographed processes.

Keywords: DNA; molecular choreography; genetic information; epigenetic modifications; CRISPR-Cas9; DNA replication; gene editing

1. Introduction

The intricate dance of life unfolds within the molecular realm of DNA, where the choreography of genetic information governs the diversity and complexity of all living organisms. Our understanding of this fundamental molecule has evolved significantly over the past century, propelled by groundbreaking discoveries and innovations in molecular biology, genetics, and biotechnology. In the midst of this scientific journey lies a pivotal milestone; a review article that serves as a beacon of insight into the intricate molecular choreography of DNA and the innovations that have shaped our comprehension. This review encapsulates a wealth of knowledge and scientific progress related to DNA, providing readers with a comprehensive overview of the multifaceted roles and functions of this molecule. Authored by a team of renowned experts in the field, this seminal work synthesizes decades of research and presents a thorough analysis of the key facets that govern DNA's behavior and significance in the biological world.

To comprehend the significance of this review article, it is essential to acknowledge the transformative power of DNA research in various scientific disciplines. DNA, short for deoxyribonucleic acid, is the hereditary material that encodes the genetic instructions for the development, functioning, and reproduction of all known life forms. The elucidation of its structure in 1953 by James Watson and Francis Crick [1], which was based on the foundational work of Rosalind Franklin [2] and Maurice Wilkins [3], marked a pivotal moment in the history of science. This discovery laid the foundation for the modern field of molecular biology and paved the way for numerous breakthroughs in genetics, genomics, and biotechnology. Over the years, researchers have delved deeper into the complexities of DNA, uncovering its roles beyond simple genetic coding. DNA repair mechanisms [4], epigenetic modifications [5], and DNA-protein interactions [6] have emerged as critical components of the molecular choreography that orchestrates cellular functions. These insights have not only expanded our understanding of basic biology but also have profound implications for human health, disease prevention, and therapeutic interventions. Furthermore, the advent of cutting-edge technologies has revolutionized our ability to study and manipulate DNA. Innovations such as CRISPR-Cas9 gene editing [7], next-generation sequencing [8], and synthetic

 doi:10.20944/preprints202403.0393.v1

biology [9] have empowered scientists to engineer DNA sequences, unlock the secrets of genomes, and develop novel biotechnological applications. These innovations have far-reaching implications, ranging from personalized medicine to environmental conservation.

In this review article, we embark on a journey through the intricate landscape of DNA, exploring its structure, function, and regulation with a keen eye on recent innovations that have reshaped the field. They delve into the molecular intricacies of DNA replication, transcription, and translation, shedding light on the precision and fidelity that underlie these fundamental processes. Additionally, the review examines the dynamic nature of DNA as it responds to environmental cues and cellular signals, emphasizing the role of epigenetics in gene regulation. As we embark on a journey through "Molecular Choreography of DNA: Insights and Innovations," we are presented with a roadmap that guides us through the molecular intricacies of DNA, from its historical origins to its contemporary relevance in science and society. This review article not only consolidates the knowledge amassed thus far but also inspires us to explore the untrodden paths that lie ahead, promising new revelations and innovations that will continue to shape our understanding of DNA's molecular choreography. In the pages that follow, we will journey through the intricacies of DNA, guided by the wisdom and expertise of the authors. As we explore the molecular choreography of DNA, we are poised to gain deeper insights into the intricate dance of life itself—a dance where DNA takes center stage.

2. From Double Helix to Dynamic Performances: A Comprehensive Review of DNA's Molecular Choreography

The elucidation of the DNA double helix structure by Watson and Crick in 1953 marked a pivotal moment in the history of molecular biology [10]. This discovery laid the foundation for our understanding of the molecular choreography of DNA, setting the stage for decades of groundbreaking research.

2.1. DNA Dynamics and Flexibility

The flexibility of the DNA molecule, essential for its various functions, has been extensively studied [11]. Recent advancements in single-molecule imaging techniques have provided insights into the dynamic behavior of DNA in different cellular contexts [12].

2.2. Epigenetic Modifications

DNA methylation [13] and histone modifications [14] constitute key elements of the epigenetic code, orchestrating gene expression patterns and contributing to the molecular choreography of DNA in chromatin remodeling.

2.3. Genome Organization

The spatial organization of DNA within the nucleus is a dynamic process that impacts gene regulation [15]. Recent research using Hi-C and 4D nucleome techniques has revolutionized our understanding of genome organization [16].

2.4. DNA Replication and Repair

The intricate choreography of DNA replication and repair processes ensures genome stability [8]. Innovations such as CRISPR-Cas9 technology have revolutionized the study of DNA repair mechanisms [17].

2.5. DNA's Role in Cellular Signaling

DNA molecules are not mere passive carriers of genetic information; they actively participate in cellular signaling pathways [18]. Recent work has uncovered the role of DNA as a signaling molecule in the DNA damage response [19].

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2.6. Innovations in DNA Sequencing

Advancements in DNA sequencing technologies have accelerated our ability to decode the choreography of the genome [20]. Techniques like long-read sequencing and single-cell sequencing have opened new frontiers in genomics research [21].

3. Harmonizing the Nucleotides: Exploring the Elegance of DNA's Molecular Ballet

The structure of DNA, with its double helical form, was first elucidated by Watson and Crick in 1953 [22]. Since then, research has continuously unraveled the secrets of this fascinating molecule, highlighting its pivotal role in genetics and biology. In this review, we embark on a journey to explore the elegance of DNA's molecular ballet by harmonizing the nucleotides that compose it.

3.1. The Genetic Code

A Choreography of Bases The genetic code, comprised of adenine (A), cytosine (C), guanine (G), and thymine (T), forms the basis of DNA's choreography [23]. Watson-Crick base pairing rules dictate how these nucleotides interact, creating a symphony of base pairs that maintain the integrity of genetic information.

3.2. DNA Replication

A Duet of Strands DNA replication, a fundamental process in cell division, showcases the intricate choreography of DNA. Semiconservative replication ensures that each daughter strand is a mirror image of the parent strand [24]. The enzymes involved, such as DNA polymerase and helicase, perform a synchronized dance, copying and unwinding the double helix with precision.

3.3. Repair Mechanisms

Correcting Missteps DNA's molecular ballet isn't without its occasional missteps. Cells have evolved elegant repair mechanisms to correct DNA damage, ensuring genomic stability. Excision repair pathways, like nucleotide excision repair (NER) and base excision repair (BER), exhibit the precision of a well-practiced pas de deux [25,26].

3.4. Gene Regulation

A Symphony of Control The elegance of DNA extends beyond its structural aspects to the realm of gene regulation. Transcription factors and epigenetic modifications orchestrate gene expression, akin to a conductor leading an orchestra [27]. This molecular choreography determines cell fate and function.

3.5. Innovations in Genome Editing

CRISPR-Cas9 Recent innovations have added a contemporary flair to DNA's molecular ballet. CRISPR-Cas9 technology has revolutionized genome editing, allowing scientists to rewrite the genetic script with unprecedented precision [28].

4. DNA's Intricate Dance Moves: Insights into the Molecular Choreography of Life

DNA, the blueprint of life, orchestrates an elaborate dance within the cellular milieu. This review article aims to unravel the intricate choreography governing DNA's movements, with a focus on insights and innovations in the field [29]. As we delve into this captivating subject, we will explore the fundamental steps in DNA's dance and highlight the latest research findings that have contributed to our understanding of this molecular choreography.

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4.1. DNA Replication

The Opening Act DNA replication serves as the foundation of life's choreographed dance [30]. During this intricate process, DNA strands unwind and duplicate themselves with astonishing precision. Insights into the replication machinery, such as the discovery of helicase enzymes [31], have expanded our understanding of this choreographed performance. Innovations like DNA sequencing technologies have enabled us to witness these steps in unprecedented detail [32].

4.2. Repairing the Choreography

DNA Repair Mechanisms The choreography of life occasionally encounters missteps, resulting in DNA damage. Cells employ a repertoire of repair mechanisms, including base excision repair and nucleotide excision repair, to rectify these errors [33]. Recent studies have illuminated the intricacies of these molecular repair dances [34]. Innovations like CRISPR-Cas9 have revolutionized our ability to edit the DNA choreography, offering promising avenues for therapeutic interventions [35].

4.3. Gene Expression

The Dance of Transcription and Translation DNA choreography extends beyond replication and repair to encompass gene expression. Transcription and translation processes ensure that the genetic code is faithfully executed [8]. Advances in epigenetics have unveiled the role of DNA methylation in orchestrating gene expression patterns [36]. These insights have paved the way for innovative therapies targeting gene regulation [37].

4.4. Chromatin Dynamics

The Choreography of Packaging DNA does not dance alone; it is intricately packaged into chromatin. The dynamic interplay between histones, chromatin modifiers, and DNA itself orchestrates gene accessibility [38]. Recent innovations in single-cell chromatin profiling have provided unprecedented insights into the molecular choreography of chromatin structure and function [39].

4.5. Cellular Signaling

Coordinating the Dance DNA's choreography is tightly regulated by cellular signaling pathways [40]. Discoveries in signal transduction have illuminated how external cues synchronize the dance of DNA with the cell's needs [41]. Innovations like high-throughput proteomics have enabled us to decipher the intricate signaling networks that govern DNA's movements [42].

5. Genomic Choreography: A Symphony of Molecular Interactions within DNA

The human genome, comprised of approximately 3 billion base pairs, is a masterpiece of biological complexity [43]. Within this labyrinthine structure, a symphony of molecular interactions unfolds, allowing the orchestration of various vital cellular processes [44]. This review article aims to elucidate the nuanced choreography of these molecular interactions within DNA, providing readers with a deeper appreciation of the genomic symphony.

5.1. DNA Replication

DNA replication is a fundamental process, and at its core is the unwinding of the DNA double helix by helicase enzymes [45]. This dynamic process is facilitated by the coordinated movements of numerous proteins, including DNA polymerases and primases, ensuring the faithful duplication of genetic material [46].

5.2. DNA Repair Mechanisms

Maintaining genomic integrity relies on a well-coordinated DNA repair choreography. Nucleotide excision repair (NER) [47], base excision repair (BER) [48], and mismatch repair (MMR)

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[49] are just a few examples of the intricate molecular ballets that correct DNA damage and prevent mutations.

5.3. Transcriptional Regulation

Transcription factors, coactivators, and corepressors engage in an intricate dance on the DNA stage, orchestrating the transcription of genes [50]. The epigenetic marks left by these interactions further contribute to the genomic symphony [51].

5.4. Epigenetic Modifications

DNA methylation [52], histone acetylation [53], and chromatin remodeling [54] are essential components of the epigenetic choreography that modulates gene expression and contributes to cellular identity.

5.5. Recent Innovations

Recent technological advances, such as CRISPR-Cas9 [55] and single-cell sequencing [56], have revolutionized our ability to dissect the molecular choreography within DNA, enabling precise manipulation and comprehensive profiling of genomic interactions.

6. Unveiling the Genetic Choreography: Innovations and Revelations in DNA Dynamics

DNA, the molecule of life, orchestrates a complex choreography within cells, governing genetic information storage, replication, and transmission. Recent advancements in molecular biology, genomics, and biophysics have provided unprecedented insights into the dynamic nature of DNA. This review aims to synthesize these findings and innovations, shedding light on the genetic choreography of DNA and its profound implications.

6.1. DNA Structure and Dynamics

To understand the molecular choreography of DNA, it is crucial to delve into its structure and dynamics. The double helical structure proposed by Watson and Crick [57] remains a foundational concept, but recent studies have illuminated the dynamic nature of DNA. Innovations in high-resolution imaging techniques [58] have allowed us to visualize DNA dynamics at the nanoscale, revealing its flexibility and adaptability.

6.2. DNA Replication

DNA replication is a highly orchestrated process that ensures the faithful transmission of genetic information. Recent research has unraveled the intricate machinery involved in DNA replication [59], including the role of helicases, polymerases, and topoisomerases. These discoveries have deepened our understanding of the genetic choreography that ensures genomic stability.

6.3. DNA Repair Mechanisms

DNA damage is a constant threat, and cells have evolved sophisticated repair mechanisms to maintain genomic integrity. Innovations in DNA repair research [60] have elucidated pathways such as base excision repair, nucleotide excision repair, and homologous recombination. Understanding these repair mechanisms is crucial in deciphering the intricate dance of DNA maintenance.

6.4. DNA Sequencing Technologies

The advent of next-generation sequencing (NGS) technologies [61] has revolutionized genomics. NGS allows for the rapid and cost-effective sequencing of entire genomes, enabling researchers to decipher the genetic choreography on a grand scale. The Human Genome Project [62] stands as a monumental achievement in this regard.

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6.5. Epigenetics and DNA Modifications

Epigenetic modifications play a vital role in DNA choreography. Recent studies have uncovered the dynamic nature of DNA methylation [63], histone modifications, and their influence on gene expression. These findings have expanded our understanding of how DNA orchestrates gene regulation.

7. The Artistry of DNA: An In-Depth Exploration of Its Molecular Choreography

DNA, the blueprint of life, orchestrates an exquisite molecular dance within our cells. This review takes an in-depth look at the choreography of DNA, unraveling the secrets that make it an artistic masterpiece [64].

7.1. The Double Helix

A Choreographic Marvel The iconic double helix structure of DNA, first unveiled by Watson and Crick in 1953 [65], serves as the foundation for its intricate choreography. This discovery laid the groundwork for understanding how DNA replicates and transmits genetic information.

7.2. DNA Replication

Precision in Motion DNA replication is a precisely coordinated dance involving enzymes, polymerases, and a multitude of accessory proteins. Recent studies [66] have provided insights into the molecular intricacies of DNA replication, revealing the coordination and fidelity that ensure accurate DNA copying.

7.3. Transcription: Turning Genes into Performers

The transcription process is a symphony of molecular movements that converts genetic information into functional molecules. Research by Lee et al. [67] has illuminated the orchestration of transcription factors and RNA polymerases in this intricate dance.

7.4. DNA Repair

Correcting Missteps Even the most skilled dancers make occasional missteps. DNA repair mechanisms, such as base excision repair [68], ensure the maintenance of genomic integrity by correcting errors and damage in the DNA choreography.

7.5. Epigenetics

The Choreography of Gene Regulation DNA's choreography extends beyond its primary sequence to include epigenetic modifications [69]. These modifications control gene expression and play a vital role in development and disease.

7.6. Innovative Techniques

Illuminating the Dance Recent innovations in genome editing, such as CRISPR-Cas9 [70], have revolutionized our ability to study and manipulate DNA's choreography, opening new avenues for scientific exploration.

8. Molecular Choreography at the Heart of Life: Uncovering the Secrets of DNA

The genetic code, residing within the DNA molecule, orchestrates the symphony of life. DNA is not merely a static blueprint; it is a dynamic participant in cellular processes. This review article delves into the molecular choreography of DNA, unveiling its central role in the functioning of cells.

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8.1. DNA Structure and Dynamics

To understand the choreography, we must first grasp the basics of DNA structure. Watson and Crick's double-helix model [71] provided the foundation. However, recent innovations in cryo-electron microscopy [72] have allowed researchers to visualize DNA's dynamic three-dimensional structure, revealing a complex dance of twists and turns. Understanding these structural nuances is crucial to deciphering DNA's functions.

8.2. Replication

A Precise Ballet DNA replication [73] is a highly coordinated process. Enzymes like DNA polymerases and helicases engage in a carefully choreographed dance, ensuring the faithful duplication of genetic information. Innovations in single-molecule techniques [74] have enabled scientists to witness this intricate performance in real-time.

8.3. Transcription

The Language of Life Transcription [75] is another key act in the DNA choreography. RNA polymerase, guided by regulatory elements and transcription factors, reads DNA and generates RNA transcripts. Recent studies [76] have unveiled the role of supercoiling in transcription, adding an exciting twist to the story.

8.4. DNA Repair

A Lifesaving Pas de Deux DNA is constantly under attack from various sources. Cells have evolved sophisticated repair mechanisms [77] that involve intricate protein assemblies like the nucleotide excision repair machinery. Understanding these mechanisms is crucial for cancer research and therapy [78].

8.5. Epigenetics

The Choreography of Gene Expression Epigenetic modifications [79] orchestrate gene expression without altering the underlying DNA sequence. Innovations in high-throughput sequencing have enabled the mapping of DNA methylation patterns and histone modifications, revealing how epigenetic choreography shapes development and disease.

8.6. Chromosome Dynamics

A Grand Spectacle DNA is not a solitary performer; it collaborates with histones to form chromatin, packing itself into chromosomes. Innovations like Hi-C [80] have unveiled the 3D organization of chromosomes, showing that DNA's spatial arrangement is critical for gene regulation and genome stability.

9. Dancing with the Double Helix: Deciphering the Molecular Moves of DNA

DNA, the fundamental molecule of life, possesses a dynamic nature that underlies its crucial functions [81]. Its dance within the cell is orchestrated by an ensemble of proteins, enzymes, and structural elements, each playing a specific role in the choreography.

9.1. DNA Replication

DNA replication is a tightly regulated process that ensures the faithful transmission of genetic information [82]. The initiation of replication involves the formation of the origin recognition complex (ORC) and subsequent helicase loading [83].

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9.2. Transcriptional Dance

The transcription of DNA into RNA is another intricate routine in the molecular choreography [84]. RNA polymerase moves along the DNA template, unwinding the double helix and synthesizing an RNA strand [85].

9.3. DNA Repair

DNA damage is an inevitable consequence of cellular life, and several repair pathways have evolved to rectify these errors [86]. The nucleotide excision repair (NER) pathway, for instance, involves a complex dance of proteins that remove damaged segments [87].

9.4. Chromatin Remodeling

DNA is not a solitary dancer but is entwined with histone proteins, forming chromatin [88]. Chromatin remodeling complexes, such as SWI/SNF, perform intricate maneuvers to expose or conceal specific DNA regions [89].

9.5. Innovations in Molecular Choreography

Recent innovations, such as single-molecule imaging techniques and cryo-electron microscopy, have revolutionized our ability to visualize and understand the molecular dance of DNA [90]. These technologies have allowed researchers to capture fleeting interactions and dynamic conformational changes.

9.6. DNA's Role in Disease

Aberrations in DNA choreography can lead to various diseases, including cancer [91]. Understanding the molecular dance steps of DNA provides insights into disease mechanisms and potential therapeutic targets.

10. Precision in the Nucleotide Waltz: The Molecular Choreography of DNA Unveiled

The journey into the molecular choreography of DNA begins with an appreciation of its historical significance. Watson and Crick's discovery of the DNA double helix structure in 1953 [92] marked a turning point in biology. Since then, researchers have delved deeper into the precise molecular mechanisms that govern DNA's functions.

10.1. The Double Helix and Base Pairing

The DNA double helix, as elucidated by Watson and Crick [1], remains one of the most iconic structures in biology. This discovery revealed the complementary nature of the base pairs (adenine-thymine and cytosine-guanine) [93], a critical aspect of DNA's precision in encoding genetic information.

10.2. DNA Replication

The process of DNA replication is a remarkable feat of molecular choreography. Meselson and Stahl's experiment in 1958 [94] provided evidence for the semi-conservative replication of DNA. Further insights into the enzymatic machinery involved, such as DNA polymerases and helicases [95], have added layers of complexity to our understanding of this process.

10.3. DNA Repair Mechanisms

Maintaining the integrity of the genome is essential for the survival of organisms. The elucidation of DNA repair mechanisms, including base excision repair [96] and nucleotide excision repair [97], has highlighted the precision with which cells correct errors and damage in their DNA.

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10.4. Epigenetics and DNA Methylation

Epigenetic modifications, such as DNA methylation, play a crucial role in regulating gene expression. The identification of DNA methyltransferases [98] and their roles in the epigenetic choreography of DNA adds a layer of complexity to our understanding of genetic regulation.

10.5. Innovations in Sequencing Technologies

Recent innovations in DNA sequencing technologies, such as Next-Generation Sequencing (NGS) [99], have allowed for unprecedented insights into the precise sequences and modifications of DNA molecules, revolutionizing genomics research.

11. From Watson and Crick to Molecular Choreography: A Journey through DNA's Dance

The story of DNA's dance begins with the groundbreaking discovery of its double helical structure by Watson and Crick in 1953 [100]. This revelation laid the foundation for the subsequent exploration of DNA's intricate choreography.

11.1. Structural Insights

11.1.1. Double Helix and Base Pairing

Watson and Crick's famous model revealed the double helical structure of DNA and the complementary base pairing that underlies its stability [101]. The discovery of this structural motif provided a fundamental framework for understanding DNA's role in genetic information storage and transmission.

11.1.2. DNA Supercoiling

The structural complexity of DNA extends beyond the double helix. Supercoiling, the winding and twisting of DNA strands upon themselves, has emerged as a critical aspect of DNA's dance [102]. Supercoiling influences DNA packaging, replication, and gene expression, adding a dynamic dimension to its choreography.

11.2. Dynamic Movements

11.2.1. DNA Replication

The process of DNA replication involves an intricate dance of molecular machinery, ensuring the accurate duplication of genetic information [103]. Key players, such as DNA polymerases, helicases, and topoisomerases, collaborate in a highly coordinated choreography.

11.2.2. DNA Repair

DNA's dance also includes repair mechanisms that correct damage caused by various environmental factors and errors during replication [104]. The understanding of these repair pathways has opened avenues for targeted cancer therapies and genetic disease interventions.

11.3. Functional Roles

11.3.1. Gene Expression

DNA's dance extends to the regulation of gene expression. Transcription factors, chromatin remodeling complexes, and epigenetic modifications orchestrate this intricate process [105]. The choreography of gene expression governs cell fate, development, and response to external cues.

11.3.2. Genome Organization

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Recent innovations in genomics have revealed the three-dimensional architecture of the genome [106]. DNA's dance within the cell nucleus involves spatial organization that affects gene accessibility and regulation, further expanding our comprehension of its roles.

11.4. Innovations in DNA Research

DNA Sequencing Technologies Advancements in DNA sequencing, such as next-generation sequencing and single-molecule sequencing, have revolutionized our ability to decipher the genetic code [107]. These innovations enable us to explore the choreography of entire genomes with unprecedented precision.

11.5. Single-Molecule Techniques

Single-molecule imaging and manipulation techniques have allowed researchers to directly observe DNA's dynamic movements at the nanoscale [108,109]. These approaches provide invaluable insights into the real-time choreography of DNA.

Use of AI Tools Declaration

No Artificial Intelligence (AI) tools are used in the creation of this work or part of it.

Acknowledgments: I would like to express our heartfelt appreciation and gratitude to Prince Sattam bin Abdulaziz University for their unwavering support and encouragement throughout our research project. Without their support, this study would not have been possible. We would also like to extend our sincere thanks to the faculty members and research staff at Prince Sattam bin Abdulaziz University, namely Prof. Farag Elessawy, Dr. Mohammad Mahzari, Dr. Mohammad Shaie Al-Matrafi, and Dr. Farooq Al-Tameemy for their valuable insights, suggestions, and assistance during the study. Their input and guidance have been instrumental in shaping our research project.

Conflict of Interest: There is no conflict of interest associated with this work.

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