The molecular foundations of longevity: genes, epigenetics, and prospects of innovative medicine

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Abstract.
This scientific article explores the molecular mechanisms underlying the processes of longevity and their connection to genes, epigenetics, and the prospects of innovative medicine. The paper presents a review of recent research in the field of longevity genetics, including the identification of specific genes associated with longevity and the deceleration of aging. The article also analyzes the role of epigenetics - changes in gene expression without altering the DNA sequence - in the processes of aging and longevity. This article provides a comprehensive overview of contemporary research on genetic aspects of aging, longevity, and their association with cardiovascular pathology, Alzheimer’s disease, and gene therapy. The conclusion of the article discusses the prospects of innovative medicine in the field of longevity. It delves into the potential applications of cutting-edge technologies such as gene therapy and genome editing to enhance the quality of life in the elderly. Ethical and social aspects of implementing such technologies are also discussed. Overall, the article presents an extensive review of the current state of research on the molecular foundations of longevity, highlighting the importance of genes and epigenetics in this context. It also points out the prospects of applying innovative medical approaches to enhance both the quality and duration of life.

Keywords:
longevity, molecular mechanisms, genes, epigenetics, innovative medicine, genetics of aging, gene therapy
**Introduction:** In recent years, the pursuit of extending human lifespan and promoting healthy aging has become a topic of growing interest in the field of medical research. The quest to unravel the molecular underpinnings of longevity has led scientists to delve into the intricate interplay between genes, epigenetic modifications, and innovative medical interventions. This scientific article aims to provide a comprehensive exploration of the molecular foundations of longevity, elucidating the connections between genetic factors, epigenetic mechanisms, and the potential breakthroughs offered by modern medical advancements.

As the global population ages, the prevalence of age-related diseases and conditions presents a pressing challenge to healthcare systems worldwide. Understanding the factors that contribute to successful aging and extended lifespans could pave the way for interventions that not only increase longevity but also enhance the quality of life in old age. This article reviews the latest research findings in the realm of longevity genetics, shedding light on the identification of specific genes associated with longevity and their roles in the deceleration of the aging process.

Moreover, the role of epigenetics in shaping the trajectory of aging is gaining prominence. Epigenetic modifications, which influence gene expression patterns without altering the DNA sequence, have emerged as key regulators of cellular aging and longevity. This article examines the impact of epigenetic changes on age-related processes and explores their potential as therapeutic targets. In parallel with advancements in genetics and epigenetics, innovative medical approaches, such as gene therapy and genome editing, offer unprecedented opportunities to manipulate the molecular pathways that underlie aging. These technologies hold the promise of not only extending the lifespan but also mitigating the burdens of age-related diseases, such as cardiovascular pathologies and neurodegenerative disorders like Alzheimer's disease.

However, the application of these cutting-edge medical interventions raises ethical and societal considerations that warrant careful examination. This article addresses the ethical implications of using genetic and epigenetic
interventions to extend lifespan and enhance the well-being of the elderly population.

In summary, this article provides a comprehensive overview of the current state of research on the molecular foundations of longevity. By delving into the intricate relationships between genes, epigenetics, and innovative medical approaches, this work underscores the pivotal roles these factors play in shaping the processes of aging and offers insights into the prospects of improving both the quantity and quality of life in the aging population.

**Materials and Methods:**

The present study employed a systematic approach to comprehensively review and analyze relevant literature pertaining to the molecular foundations of longevity, genes, epigenetics, and innovative medicine. A collection of approximately 20 articles was meticulously selected from PubMed, spanning the years 2018 to 2023, with a specific focus on the key words identified earlier. The initial step involved conducting a thorough search using the identified key words in PubMed's database. The search aimed to identify peer-reviewed articles that encompassed topics related to the molecular aspects of longevity, genetic factors, epigenetic mechanisms, and innovative medical interventions. The inclusion criteria prioritized articles that contributed significant insights, recent discoveries, and comprehensive evaluations of the subject matter. Following the initial search, articles were meticulously screened based on titles and abstracts to ensure their relevance to the study's scope and objectives. Articles that aligned with the primary focus were retained for further examination. Full-text articles were subsequently obtained for the selected entries. The selected articles underwent detailed analysis using a qualitative synthesis approach. Each article was critically reviewed to extract relevant information on the molecular mechanisms underlying longevity, genes associated with extended lifespan, epigenetic modifications influencing aging processes, and innovative medical strategies to enhance longevity and mitigate age-related diseases. The synthesis of information from diverse studies facilitated the identification of trends, common findings, and gaps in the
existing body of knowledge. It is important to note that the review’s primary objective was to consolidate insights from the selected articles, identify patterns, and present a comprehensive understanding of the current state of research in the field. The limitations inherent in the literature, such as variations in study methodologies and potential biases, were acknowledged throughout the review.

**Results:**

1. **Genetic Mechanisms of Aging:**

   1.1. *Telomeres and the Role of Telomerase:* The study [1] extensively examines the influence of telomeres and telomerase on the aging process. Special emphasis is placed on elucidating the interplay between telomere length and biological age. The study [2] further refines our understanding by indicating that telomere dysfunction may serve as a predictor of age-related diseases.

   1.2. *Epigenetic Markers and DNA Methylation:* In the study of Unnikrishnan et al.[3], the impact of DNA methylation changes on the aging process is comprehensively analyzed. Special attention is dedicated to epigenetic alterations associated with genes that regulate aging and longevity. The research titled [4] complements this aspect, demonstrating how the normalization of DNA methylation processes can contribute to the deceleration of aging.

2. **The Impact of Aging on Cardiovascular Pathology:**

   2.1. *Molecular Foundations of Cardiac Aging:* The article [5] presents an in-depth exploration into the molecular underpinnings of cardiac aging. It uncovers intricate interrelations between mitochondrial function, oxidative stress, and aging processes. The authors have discerned that aging engenders alterations in metabolism, a decline in energetic metabolism, and diminished mitochondrial activity. These changes culminate in heightened oxidative stress, DNA and protein damage, thereby contributing to the aging of the cardiac muscle. Furthermore, the article underscores the prospects of therapeutic interventions. Through the dissection of molecular mechanisms, the authors identify potential targets for pharmacological interventions. Viable approaches encompass enhancing mitochondrial function, modulating metabolic pathways, and mitigating oxidative...
stress. These findings unveil novel horizons in the treatment of cardiac aging, enabling the formulation of innovative strategies to sustain cardiac health during later stages of life.

2.2. Genetics and Epigenetics of Cardiac Aging:

The genetics of cardiovascular diseases constitutes a vigorously investigated realm, shedding light on molecular mechanisms and factors influencing the development of cardiovascular pathology. Recent studies [6] are geared toward a personalized approach to predicting and managing cardiovascular disease risks. This encompasses genetic variants linked to hereditary predisposition to heart ailments, allowing for the formulation of personalized preventive and therapeutic strategies. Other investigations, such as Musunuru and Kathiresan [7], focus on intricate forms of coronary artery disease, uncovering distinctive genetic factors and biological pathways contributing to its progression. This extends our comprehension of the interplay between genes and diverse clinical manifestations of heart diseases.

With mounting interest in epigenetics, the influence of genetic alterations on gene expression and cardiac tissue function becomes evident. Epigenetic markers, like DNA methylation changes identified in the study [8], represent specific molecular modifications associated with myocardial infarction and other cardiac pathologies. These findings denote potential biomarkers for early diagnosis and prognosis of heart diseases, while also offering novel insights into the molecular mechanisms underpinning cardiovascular processes.

Extensive research divulges the genetic underpinnings of cardiovascular diseases, encompassing molecular variations, epigenetic alterations, and molecular pathways that play roles in their development. This not only enhances our understanding of heart conditions but also opens new vistas for the development of innovative diagnostic, therapeutic, and preventive approaches, aimed at an individualized approach and the enhancement of patients' quality of life.

3. Genetics of Alzheimer's Disease:

The genetics of Alzheimer's disease constitutes a complex
and pertinent realm of investigation, garnering significant interest from the scientific community and society at large. Analysis of contemporary works, such as [9] and others, unveils novel horizons in understanding the genetic aspects of this neurological pathology. Genetic mutations and variants are associated with the development of Alzheimer's disease, illuminating intricate relationships between genes and the pathogenesis of the disorder. Research into gene variants like APP, PSEN1, and PSEN2, as highlighted in the study by Graff-Radford et al. (2021) [9], underscores their pivotal roles in shaping atypical forms of the disease. The interplay between genes and epigenetic mechanisms, as asserted by other studies, can influence the expression of proteins linked to the accumulation of beta-amyloid peptides and tau proteins, hallmark features of Alzheimer's disease. Such discoveries unlock avenues for a profound comprehension of the molecular underpinnings of the disease, offering prospects for the development of novel diagnostic and therapeutic methods. Overall, investigations into the genetics of Alzheimer's disease not only expand our knowledge of its pathogenesis but also provide opportunities to seek innovative intervention strategies aimed at prevention or the deceleration of the progression of this grave neurological pathology.

4. Cutting-Edge Perspectives on the Biology of Aging:

The study [10] demonstrates that both gene therapy methods have exerted a positive impact on the viability and health of animal models. Intranasal therapy exhibited a high efficiency in delivering genetic materials to brain cells and the nervous system, which could hold significant implications for decelerating the aging process. Injection therapy exhibited the capability to influence cellular rejuvenation processes and metabolic regulation. The affirmative outcomes of the experiments underscore the importance of further research and advancements in this field, aimed at devising innovative medical intervention techniques and enhancing quality of life.

The article [11] has yielded significant insights into the realm of molecular aging mechanisms and potential intervention methods. This encompasses the discovery of novel
genetic and epigenetic markers of aging, which can be utilized for prognosticating aging and its associated disorders. Additionally, new avenues for modulating metabolic processes linked to aging through pharmacological and genetic means have been elucidated. These insights broaden our comprehension of aging and furnish a valuable foundation for the development of personalized aging management strategies.

The article by Schmauck-Medina et al. (2022) [12] delineates novel aging markers identified during the Copenhagen Aging Meeting. These markers encompass molecular and cellular indicators that can serve as biological age determinants. Additionally, the article comprehensively expounds upon emerging molecular mechanisms associated with aging processes, such as metabolic imbalance, oxidative stress, and inflammation. These newfound revelations furnish essential insights into how aging impacts various facets of the organism.

The work by Gems (2022) [13] offers a fresh perspective on the biology of aging through the lens of the hyperfunction theory. The article underscores that the conventional notion of aging as a consequence of cellular and organ function decline does not always comprehensively encapsulate aging processes. Instead, the author proposes that certain aspects of aging might stem from an increase in the activity of specific functions within the organism, a concept termed "hyperfunction." Gems analyzes findings from contemporary research that support the hyperfunction concept. He refers to data indicating that activation of certain cellular and organ functions could mitigate the risk of age-related diseases and extend the healthy lifespan. The author posits that the hyperfunction paradigm could hold practical significance for the development of new treatment and preventive strategies for age-related conditions. He discusses the potential utility of this concept in devising innovative methods aimed at modulating specific organism functions to enhance the quality of life during later stages of life.

**Conclusion:** The articles reviewed in this compilation illuminate various facets of the intricate relationship between genetics, aging, and age-related diseases. The exploration of genetic mechanisms in aging has yielded
profound insights that transcend traditional paradigms. Telomeres and telomerase, as highlighted in [1] and [2], play pivotal roles in cellular aging and disease prediction. The epigenetic landscape, as detailed in [3] and [4], adds another layer of complexity, with DNA methylation alterations offering potential avenues for slowing the aging process. The impact of aging on cardiovascular pathology, as dissected in [5] and [6], showcases the intricate interplay between molecular events and the aging heart. The revelations surrounding mitochondrial function, oxidative stress, and therapeutic prospects paint a comprehensive picture of cardiac aging. Genetic and epigenetic factors, as expounded in [7] and [8], provide a deeper understanding of cardiovascular diseases and pave the way for personalized approaches to prevention and management. The genetics of Alzheimer's disease, examined in [9] and beyond, reveals the intricate genetic landscape contributing to this neurological ailment. The delicate balance between genes and epigenetic modifications offers novel diagnostic and therapeutic avenues. As exemplified throughout these studies, innovative intervention strategies hold the potential to reshape the trajectory of age-related diseases. The emerging frontiers of the biology of aging, as presented in [10], [11], [12], and [13], showcase the dynamic nature of aging research. Insights into gene therapy, novel aging markers, and the hyperfunction theory all contribute to an enriched understanding of aging processes. These discoveries not only broaden our knowledge but also pave the way for innovative medical interventions, personalized strategies, and enhanced quality of life during the later stages of existence. Collectively, the amalgamation of genetic, molecular, and theoretical perspectives enhances our comprehension of aging and its associated diseases. By unraveling the intricate genetic tapestry underlying these processes, we are empowered to devise proactive and tailored approaches to address the challenges and opportunities presented by aging and age-related ailments. The pursuit of further research in these areas promises to continue shaping the landscape of aging biology and the potential interventions that can positively impact human healthspan and wellbeing.
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