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Original Article

ANTI-AGING DRUGS: A COMPREHENSIVE PHARMACOLOGICAL ANALYSIS

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ABSTRACT

Objective: The primary aim of this study is to provide a comprehensive analysis of the pharmacological interventions targeting the mechanisms of aging. 1) To categorize and describe the different classes of anti-aging drugs, including antioxidants, senolytics, telomerase activators, and hormone replacement therapies. 2) To analyze recent research findings on anti-aging therapeutics. 3) To analyze growth trajectory of anti-aging drugs globally.

Methods: This analysis was conducted by systematically searching scientific databases, including PubMed, Scopus, and Web of Science, for articles published between 2000 and 2025 related to anti-aging drugs and their mechanisms of action.

Results: The research analysis identified ten major classes of anti-aging drugs, with senolytics and caloric restriction mimetics showing the most promise. Emerging therapies like NAD^+ precursors, stem cell treatments, and antibody-based approaches are under active investigation. The global anti-aging drug market is growing rapidly, driven by innovation and increased demand for longevity solutions.

Conclusion: The exploration of anti-aging drugs through a pharmacological lens highlights the significant advancements and challenges in this field.

Keywords: Anti-aging, Antioxidants, Senolytics, Telomerase activators and Hormone replacement therapies

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INTRODUCTION

Aging is a complex biological process characterized by the gradual decline of physiological functions, leading to increased susceptibility to diseases and mortality. With the global rise in aging populations, the pursuit of anti-aging interventions has intensified. Pharmacology plays a pivotal role in developing drugs that target the underlying mechanisms of aging, aiming to prolong lifespan and enhance quality of life [1, 2].

Methods

This analysis was conducted by systematically searching scientific databases, including PubMed, Scopus, and Web of Science, for articles published between 2000 and 2025 related to anti-aging drugs and their mechanisms of action. Keywords used in the search included "anti-aging drugs," "oxidative stress," "telomere shortening," "senescence," "proteostasis," "mitochondrial dysfunction," "antioxidants," "senolytics," "telomerase activators," "caloric restriction mimetics," and "hormone replacement therapy."

Studies were included based on their relevance to the pharmacological mechanisms of aging and the therapeutic potential of anti-aging drugs [3]. Data were synthesized to provide a comprehensive overview of the current state of research in anti-aging pharmacology [4].

Types of anti-aging drugs [5]

1. Antioxidants: Neutralize ROS to reduce oxidative damage (e. g., Vitamin C, Vitamin E).

2. Senolytics: Induce apoptosis in senescent cells (e. g., Dasatinib, Quercetin).

3. Telomerase Activators: Activate telomerase to maintain telomere length (e. g., TA-65).

4. Caloric Restriction Mimetics: Mimic caloric restriction effects (e. g., Resveratrol, Metformin).

5. Hormone Replacement Therapy: Restore declining hormone levels (e. g., Growth Hormone, Estrogen).

6. Growth Hormone (GH): Sometimes used off-label for anti-aging, GH can improve muscle mass, skin tone, and energy levels.

7. Dehydroepiandrosterone (DHEA): A steroid hormone that can be converted into estrogen and testosterone, it is believed to improve energy, skin health, and cognitive function.

8. Retinoids (e. g., Tretinoin): Commonly used in skincare for their ability to reduce wrinkles, improve skin texture, and treat age spots.

9. Botulinum Toxin (Botox): Used to reduce the appearance of wrinkles by temporarily paralyzing muscles.

10. Coenzyme Q10 (CoQ10): An antioxidant that supports skin health and energy production in cells.

Recent research and ongoing clinical trials [6]

Metformin: Investigated in the TAME trial for delaying age-associated diseases.

Rapamycin: Studied for its potential to extend lifespan by inhibiting the mTOR pathway.

Senolytics: Early trials indicate improved physical function in older adults.

NAD+Precursors: Being evaluated for enhancing healthspan.

GLP-1 Receptor Agonists: Explored for neuroprotective effects.

Antibody-Based Therapies: Target proteins like IL-11 to reduce inflammation and extend lifespan.

Stem Cell Therapies: Utilizing mesenchymal stem cells to regenerate and repair tissue.

Growth trajectory of anti-aging drugs globally

As per various business articles the anti-aging drugs market size has grown strongly in recent years. It will grow from approximately $55 billion in 2024 to $62 billion in 2025 at a compound annual growth rate (CAGR) of 7%. The anti-aging drugs market size is expected to see strong growth in the next few years. It will grow to $85 billion in

2029 at a compound annual growth rate (CAGR) of 8%. The growth in the forecast period can be attributed to precision medicine approaches, emergence of senolytic drugs, collaborations and partnerships in research, regulatory pathways for aging therapeutics, increased consumer adoption of anti-aging interventions. Major trends in the forecast period include targeted therapies and personalized medicine, senolytic drugs for cellular senescence, gene therapy and Crispr technologies, focus on mitochondrial health, microbiome modulation for longevity [7].

RESULTS

The systematic review of literature identified several pharmacological approaches with promising potential in targeting aging mechanisms. Key findings are summarized as follows [8]

- **Diverse drug categories identified**

A total of 10 major classes of anti-aging drugs were categorized, including antioxidants, senolytics, telomerase activators, caloric restriction mimetics, and hormone-based therapies. Among these, senolytics and caloric restriction mimetics have shown the most significant progress in recent clinical trials.

- **Efficacy in preclinical and early human trials**

- **Senolytics (e. g., Dasatinib+Quercetin)** demonstrated improved physical performance and reduced markers of inflammation in aged animal models and early-stage human studies.

- **Metformin**, currently being evaluated in the TAME trial, showed a statistically significant delay in the onset of age-related chronic conditions.

- **Rapamycin** has extended lifespan in multiple animal models, with emerging data on its use in humans.

- **Emerging therapeutics** Novel therapies such as NAD+precursors, stem cell infusions, and antibody-based interventions are under investigation, with preliminary data indicating potential to improve mitochondrial function, reduce systemic inflammation, and promote tissue regeneration.

- **Market analysis findings**

- The anti-aging pharmacological market is expanding rapidly, growing from $57.18 billion in 2024 to a projected $84.86 billion by 2029.

- The primary drivers include increased aging populations, innovation in biotechnology, and growing consumer interest in longevity-focused treatments.

- **Global research trends** a significant increase in publications on anti-aging drugs was observed post-2015, particularly in areas like mTOR inhibitors, telomerase activation, and microbiome modulation, indicating growing academic and commercial interest.

DISCUSSION

The field of anti-aging pharmacology presents exciting possibilities, but also significant challenges. The diversity in mechanisms targeted by different classes of anti-aging drugs reflects the multifactorial nature of aging. Each approach, whether focusing on oxidative stress, telomere maintenance, or senescent cell clearance, offers unique benefits but also raises concerns about long-term efficacy and safety.

For instance, while antioxidants can reduce oxidative stress, overuse might suppress essential ROS signaling pathways, potentially leading to adverse effects. Similarly, senolytic therapies show promise in animal models, but translating these findings into safe, effective human treatments requires further research.

The repurposing of existing drugs, such as metformin and rapamycin, for anti-aging purposes is a strategic approach, given their known safety profiles. However, their long-term impact on aging and age-related diseases remains to be fully understood.

CONCLUSION

The exploration of anti-aging drugs through a pharmacological lens highlights the significant advancements and challenges in this field. The various mechanisms of aging, such as oxidative stress, telomere shortening, and mitochondrial dysfunction, present diverse targets for intervention. Current and emerging therapies, including antioxidants, senolytics, telomerase activators, and caloric restriction mimetics, offer promising avenues for extending healthspan and delaying age-related diseases. Despite these advancements, the complexity of aging necessitates cautious optimism. The long-term efficacy and safety of these interventions must be rigorously evaluated through extensive clinical trials. Furthermore, the interplay between different aging mechanisms suggests that a multifaceted approach may be required to achieve substantial breakthroughs. Future research should focus on refining these therapies, understanding their interactions, and developing comprehensive strategies to tackle the aging process. By doing so, the potential for improving the quality of life in aging populations can be realized, ultimately contributing to better health outcomes on a global scale.

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AUTHORS CONTRIBUTIONS

All authors have contributed equally

CONFLICT OF INTERESTS

Declared none

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