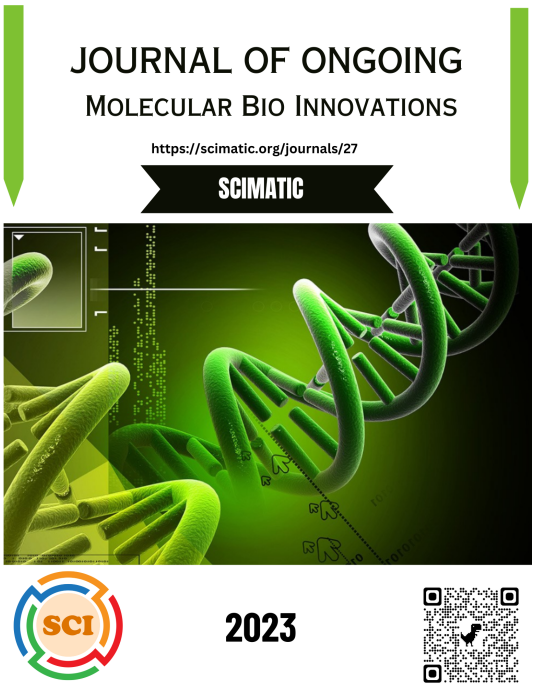
MOLECULAR MECHANISMS AND THERAPEUTIC STRATEGIES IN CUTANEOUS AGING:

A COMPREHENSIVE REVIEW



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Review

Molecular Mechanisms and Therapeutic Strategies in Cutaneous Aging: A Comprehensive Review

Mayada Luqman*
For affiliations and correspondence, see the last page.

Abstract

Skin aging is a complex biological process influenced by the interplay of intrinsic (chronological) and extrinsic (environmental) factors, culminating in visible changes such as wrinkles, laxity, and dyspigmentation. Intrinsic aging results from endogenous oxidative stress and cellular senescence, leading to reduced fibroblast proliferation, diminished collagen synthesis (notably types I and III), and fragmentation of elastin fibers. Concurrently, extrinsic aging, primarily mediated by chronic ultraviolet (UV) exposure (photoaging), exacerbates these effects through upregulation of matrix metalloproteinases (MMPs), degradation of extracellular matrix (ECM) components, and accumulation of abnormal elastin (solar elastosis). Additional contributors include decreased hyaluronic acid production, impaired barrier function, and accumulation of advanced glycation end products (AGEs). Modern anti-aging strategies target these pathways via retinoids, antioxidants, and cosmeceuticals aimed at collagen stimulation, oxidative stress neutralization, and epidermal rejuvenation. Understanding these mechanisms is critical for developing evidence-based interventions to mitigate cutaneous aging.

Keywords: Skin Aging, Antioxidants, Photoaging, Anti-aging Agents, Cutaneous Aging, Collagen Degradation, Wrinkle Formation

Skin aging is an inevitable yet multifaceted biological process characterized by progressive decline in structure and function, manifesting clinically as wrinkles, loss of elasticity, and uneven pigmentation. As the largest organ of the human body, the skin serves as both a protective barrier and a visible indicator of systemic aging, driven by the cumulative effects of intrinsic (genetic, metabolic) and extrinsic (environmental, lifestyle-related) factors [1]. Intrinsic aging, governed by chronological cellular senescence and hormonal changes, leads to reduced proliferative capacity of keratinocytes and fibroblasts, diminished collagen synthesis, and impaired wound healing [2]. In parallel, extrinsic aging—primarily mediated by ultraviolet (UV) radiation (photoaging), pollution, and smoking—accelerates these changes through oxidative stress, chronic inflammation, and extracellular matrix (ECM) degradation [3].

The global anti-aging skincare market, projected to exceed $88 billion by 2030, reflects escalating demand for interventions to counteract these processes [4]. Current strategies target key molecular pathways: retinoids to stimulate collagen production, antioxidants (e.g., vitamin C, niacinamide) to neutralize free radicals, and peptides to promote ECM synthesis [5]. However, the efficacy, safety, and accessibility of these agents vary widely, necessitating a critical evaluation of their mechanisms, clinical evidence, and practical applications.

This review synthesizes contemporary insights into cutaneous aging pathophysiology and provides a systematic analysis of leading anti-aging compounds, emphasizing:

1. **Mechanistic basis** (e.g., MMP inhibition, telomere maintenance),
2. **Clinical efficacy** (from randomized trials to real-world outcomes),
3. **Challenges** (irritation, cost, variability in response), and
4. **Emerging therapies** (senolytics, exosomes, microbiome modulation).

By bridging bench-to-bedside knowledge, this paper aims to guide researchers, clinicians, and consumers in navigating the evolving landscape of evidence-based anti-aging dermatology.

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Affiliations and Corresponding Informations

Corresponding: Syed Atta Ullah SHAH
Email: attaullahshahsyed9@gmail.com
Phone: 05060568409

Mayada Luqman:
1: Muğla üniversitesi
2: Teknopark ADÜ